COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH

THE

NEW ZEALAND JOURNAL OF SCIENCE AND TECHNOLOGY

VOLUME 29

B. GENERAL SECTION

CONTENTS

VOLUME 29, 1947-48

B. GENERAL SECTION

No. 1—July 1947

No. 2—September, 1947

No. 3—November, 1947

No. 4—January, 1948

No. 5—March, 1948

No. 6—May, 1948

THE NEW ZEALAND

JOURNAL OF SCIENCE

AND

TECHNOLOGY

Editor: D. Cairns, M.Sc. (Assistant Editor: M. O'Connor, M.Sc.), Department of Scientific and Industrial Research, Wellington.

VOL. 29, SEC. B | JULY, 1947 | NUMBER 1

GEOLOGY OF THE FOREST HILL SURVEY DISTRICT, SOUTHLAND

By M. V. ROUT, New Zealand Geological Survey

(*Received for publication, 3rd April, 1947*)

Summary

The geology of the area between the Hokonui Hills and Forest Hill is here described. The old Hokonui coal-mine, which operated in a strip of Tertiary rocks on the west flank of the Hokonui Hills, is discussed and the likelihood of the measures continuing under the Makarewa Flats to Forest Hill is suggested. Tertiary clay deposits are mentioned, including the one in which Mako clay-pit operates.

INTRODUCTION

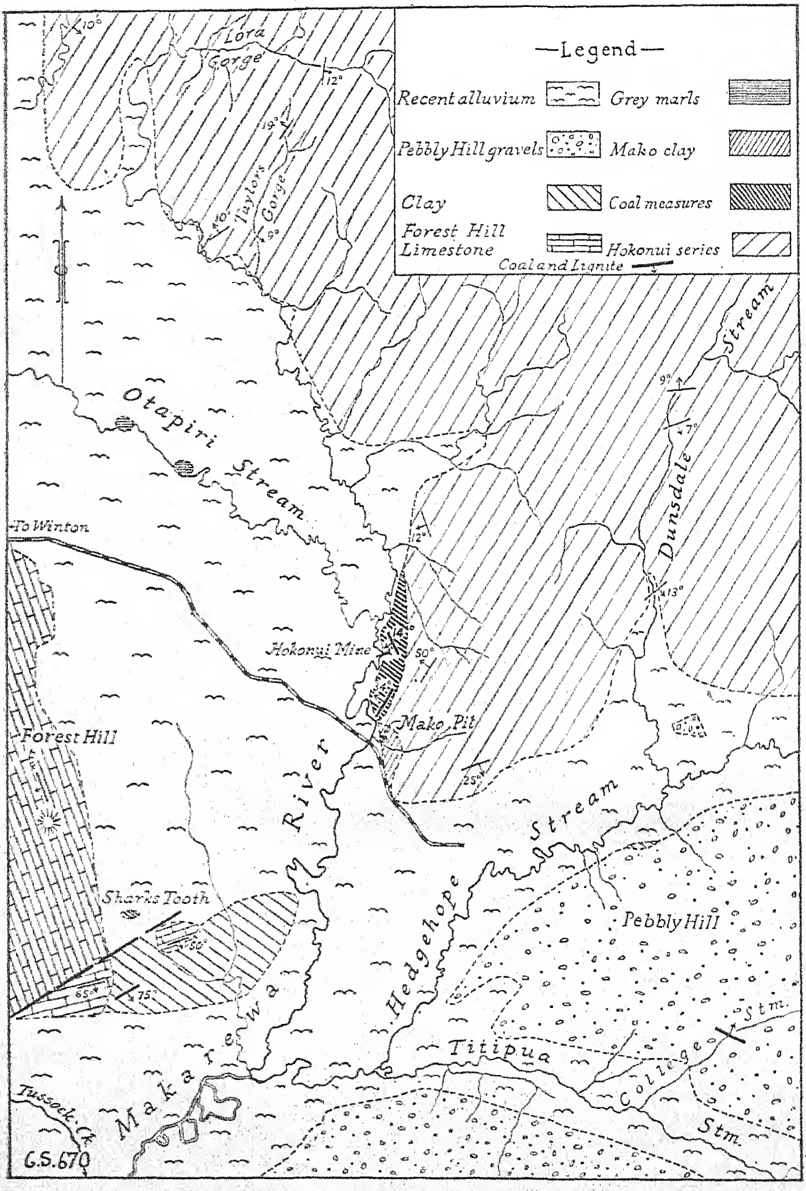
THE area examined includes the south-west flank of the Hokonui Hills, bounded to the east by the Dunsdale Stream and to the north by Lora Gorge, and the river-flats extending from the Hokonui Hills west to Forest and Winton Hills, south to the Titipua and Hedgehope Streams.

Outcrops are scarce, the hills being mainly covered with bush and scrub and the lower slopes having a fairly continuous layer of clay and soil. Coal is well exposed only at the mine and in prospect holes. On Forest Hill and Sharks Tooth Hill, limestone is fairly well exposed. Near the north boundary, Hokonui beds crop out in streams and cliff faces.

STRUCTURE

Cox (1877) carefully described the structure of the northern part of Hokonui Hills. " Near the northern boundary of the hills, steeply dipping beds form an anticline, the axis of which runs south-east from Okaiterau Stream, backing until, approaching Croydon, the axis runs east. A considerable thickness of the beds of the south-west limb are exposed. Near the Bastion these flatten out to form a trough-like syncline with the axis dipping gently to the west."

He did not extend his work south of the trough where the beds were not well enough exposed for their purpose. From what little can be seen of them, the beds here appear to be gently folded, the strike ranging from 30° to 45° east. In Taylor's Gorge the axis of an anticline may be distinguished striking 30°. Near the junction of the Otapiri and Makarewa Rivers the strike is about 45°. South of the junction the beds rise steeply to form an anticline, the axis of which strikes 20° and pitches 10° towards Mako flag station (30 chains south of the railway bridge).



Geology of Forest Hill S.D.
— SOUTHLAND —

Scale

CHAINS 80 40 0 1 2 3 MILES

To accompany "Geology of Forest Hill S.D.–Southland." by M. V. Rout, 1946

Beds of the south-east limb crop out as a level ridge, one mile long, forming the hill above Hedgehope and marking the southern boundary of the Hokonui rocks.

From about three-quarters of a mile north of the junction of the Makarewa River and the Otapiri Stream to two miles south of it, extends a strip of Tertiary rocks containing the coal-seam in which the Hokonui mine operated. The Tertiary beds are bounded to the west, at the Makarewa River, by recent fluvial beds and to the east by Hokonui beds up to about 40 chains from the river. Good dips are obtainable in the coal at the mine entrance and in prospect holes, and also in clays and sands containing calcareous-cemented bands, which crop out mainly along the river. The sand and clay that form a large part of the Tertiary beds show little stratification and do not assist in the elucidation of the structure. The beds appear to form a semi-basin, extending from just north of the mine to 8 chains north of the Mako clay-pit, dipping up to 30° to the south-west from the north end and the same to the north-west from the south end, and flattened almost horizontal in the river-banks midway between. The possibility of the flat bottom of the basin extending beneath the river-flats to Forest Hill is suggested by the presence (mentioned later) of sub-bituminous coal, overlain by calcareous mudstone, near the east side of Forest Hill.

Just north of the Mako clay-pit a spur of Hokonui rocks juts out to the river. making a break in the Tertiary strip. The rocks of this spur are strongly jointed, making bedding planes difficult to distinguish but the strike generally appears to be about 30°. The clay of the pit shows faint stratification, but owing to the rapid movement of unrestrained clay this is of little help. It appears to rise to the south, east, and west. The man working the pit says that as clay was extracted the floor of the pit continued to rise in a hump, almost certainly the result of removal of clay causing a flow. The clay is clearly fluvial transported clay. Whether it belongs to the coal-measure is doubtful. Its position, tucked in against the Hokonui rocks, may be due to faulting; possibly the clay is a remnant preserved on the down throw side of Sharks Tooth fault, here assumed to continue to the north of the pit. Alternatively, the clay may be the remains of an estuarine formation defended by spurs of Hokonui rocks.

The limestone forms the line of hills, Forest Hill, Winton Hill, Lime Hill, and Centre Bush. According to Macpherson (1937), these are Hutchinsonian and represent remnants of a syncline, the axis of which passes through Centre Bush, in the direction of 167°, leaving Lime Hill to the west, dipping gently east, and Forest Hill to the east, dipping gently west.

The limestone of Sharks Tooth Hill strikes 40° and dips south-east 50°, and in a small knoll at the south-east end of Forest Hill the limestone dips steeply to between south-east and south. This discordance with the syncline has been caused by a fault running 60° along the straight, narrow valley separating the knoll from the main part of Forest Hill and passing adjacent to Shark's Tooth Hill on its northern side.

Grey marls crop out as almost horizontal beds in the banks of the Otapiri Stream and underlie the limestone of Forest Hill.

The nature and slope of the surface underlying the Pebbly Hill gravels could not be determined, as the lower contact is in sight in one place only. The lignite in them dips to 30°.

STRATIGRAPHY

The reports of Cox and McKay (1877) were chiefly aimed at clarifying the sequence of Mesozoic beds, which in the Hokonui Hills are well displayed and very fossiliferous. McKay (1877) discussed the relation of overlying formations and stated the sequence :—

(1) Recent river gravels and raised beaches.
(2) Forest Hill limestone.
(3) Grey marls, exposed in Otapiri Stream and underlying Forest Hill.
(4) Brown coal and lignite, including quartz gravels of Pebbly Hill (Cretaceous-Tertiary).
(5) Higher plant beds, Mataura Series.
(6) Lower plant beds, Putataka Series ; older rocks of Hokonui Series.

The coal-seam in which the Hokonui mine later operated was apparently not observed. McKay would almost certainly have put it with (4), as belonging "to the brown or pitch coals of the Cretaceous-Tertiary." However, he says that the relations of (4) are obscure and puts it in this position on the grounds of lack of contradicting evidence.

In this report the sequence is considered to be :—

(1) Recent.
(2) Lignite, quartz gravels, Mako clay.
(3) Forest Hill limestone.
(4) Grey marls.
(5) Coal and clay—

Mataura Series
Putataka Series
Older rocks of Hokonui Series } Mesozoic.

(1) *Recent.*—The river-flats between Forest Hill and the Hokonui Hills consist of shingle beds with occasional peaty layers, and considerable patches of clay of doubtful ages. The beds are mostly stained with iron, and in places layers of gravel and sand are strongly iron cemented. Some of the clays clearly are recent alluvium, others, such as the clay at Tussock Creek, are older.

(2) *Lignite and Pebbly Hill Gravels.*—The gravels are very pure quartz gravels, of well-rounded, elongated pebbles from slightly less than 1 in. long down to grit size. They are white, except for pockets stained with a soft manganese powder. Some lenses of a white siliceous clay can be moulded like plasticene. A lignite-seam outcrops in College Stream, dipping gently to 30°. The ultimate origin of the gravels is accepted as being the result of erosion of quartz schist during the Cretaceous. The lack of induration of the clay that underlies them (where 10 ft. of blue clay are overlain by 3 ft. of blue sand) argues that they are no older than Tertiary. Their position in the Tertiary cannot yet be determined. They may easily be older than the Forest Hill limestone. That they are younger than the limestone is suggested by the clay beds containing lignite that overlie the limestone at the south end of Forest Hill, and by the fact that (5) contains seams of higher-ranking coal than the lignite of the Pebbly Hill, not far distant.

(3) *Forest Hill Limestone.*—A calcareous sandstone with abundant fossils (notably brachiopods and Bryozoa) and harder less-fossiliferous limestone from Forest Hill. They overlie grey marl. According to Macpherson (1937), the limestone is Hutchinsonian in age.

(4) *Grey Marl.*—Blue-grey calcareous mudstone outcrops in the banks of Otapiri Stream. Foraminiferal determinations by Dr. H. J. Finlay place the age of this marl as Whaingaroan (personal communication). This determination correlates the marl with the Whain-

garoan beds of Orepuki district and with the marl underlying the limestone of Forest Hill (Willett, personal communication).

(5) *Coal and Clay.*—The coal-measures are in the semi-basin structure near the junction of Otapiri Stream and Makarewa River, and rest unconformably on Hokonui beds. At the boundary, Putataka beds appear directly in contact with the Tertiary. The sequence is :—

(*a*) Clays, white and grey sands, both in places consolidated by lime to form hard blocks in discontinuous layers.
(*b*) Carbonaceous clays.
(*c*) Carbonaceous shales and coal.
(*d*) White sand.
Basal member not observed.

These beds vary laterally very rapidly and generally appear to have been formed under estuarine conditions.

The coal is hard, resinous with shiny black lustre, and conchoidal fracture, but shows distinct bedding planes. Thin coal stringers occur in overlying sands and muds. An outcrop in the banks of the Makarewa of hard, black coal a few inches thick, set in flat blocks themselves contained in a grey muddy clay, is of interest for the similarity to recent drill-core near Ohai, where mudstone concretions enclose a few inches of black coal. On the east side of Forest Hill, similar coal overlain by similar mudstone concretions clearly underlies the limestone.

The relations of the clay of the Mako clay-pits are obscure. There is a similar very small occurrence at the mouth of Taylor's Gorge. The clay was probably a weathering product (though not residual) of the upper Hokonui rocks, which do weather very rapidly to a fine clay. With small outcrops on the hillside above the pit, it is impossible to tell without excavating whether a clay is a recent weathering product or part of the Tertiary beds. Fragments of coal occur in the clay in the pit ; these may come from Hokonui beds that contain thin coal-seams. In the pit the clay appears in many different colours, red, blue, white, and grey, and varies in sandiness. On top is a layer a few inches thick of hard indurated blue claystone. Mako clay belongs either to the coal-measures or the clay of Tussock Creek and Pebbly Hill gravels.

The latter is suggested by the similarity of the clay underlying the Pebbly Hill gravels, and by the presence in sands associated with Mako clay of manganese stains that closely resemble the manganese staining of the Pebbly Hill gravels.

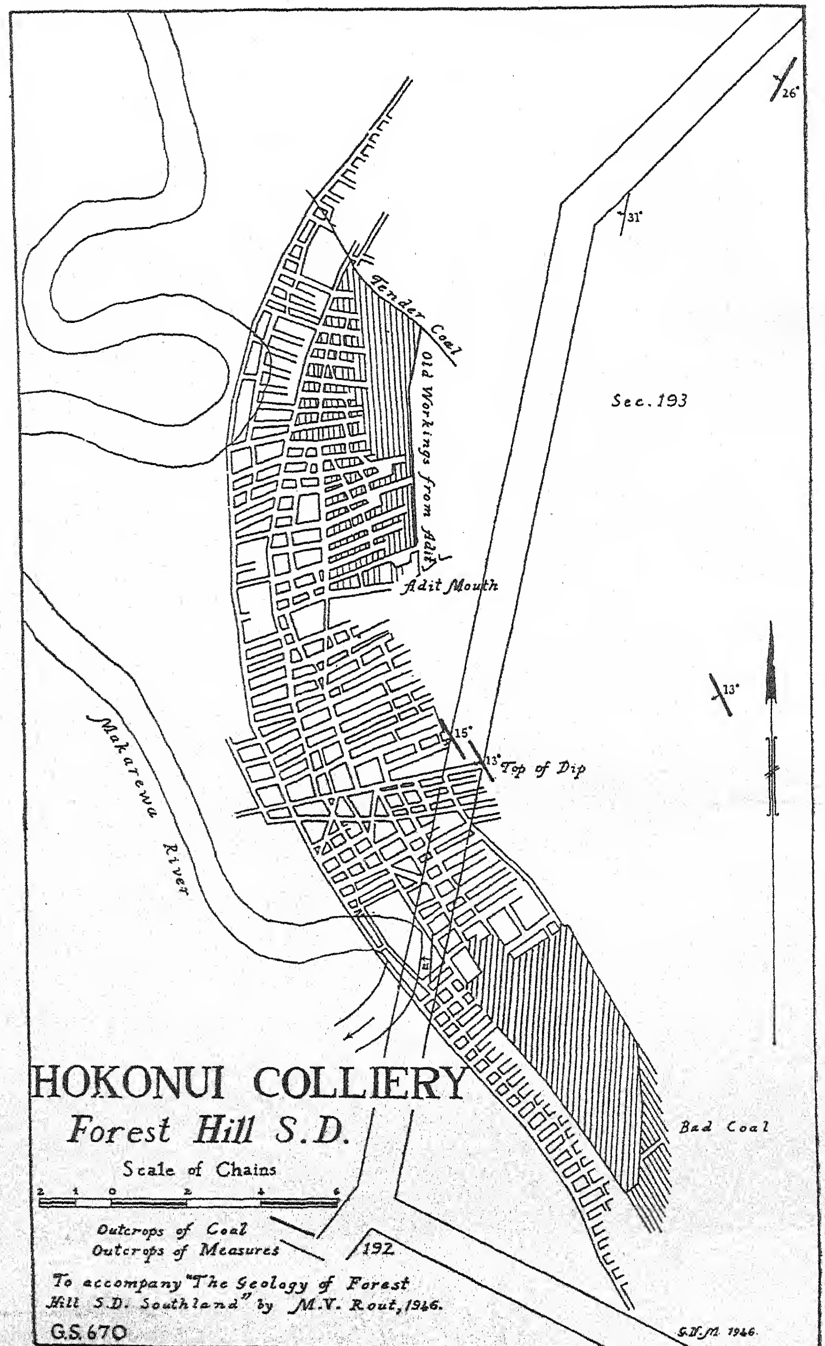
HOKONUI COAL-MINE

The lease was reported on before the opening of the mine by Park (1886). Taking an average thickness of 10 ft., he estimated the lease to contain 1,000,000 tons of coal, but, thinking the seam rose to the north and not realizing that the eastern boundary was so near the river, he probably overestimated it.

From reports in Mines Statements the Hokonui mine operated between the years 1887 and 1896 in the lease on the east side of the Makarewa, just below its junction with the Otapiri. The seam was 7-12 ft. thick, dipping 14° to the west. The mine started in 12 ft., but the top two divisions of 3 ft. and 1 ft. faded into carbonaceous clay. The coal was similar to that at Nightcaps. It was a good steaming coal and was used by the railways.

In 1894, at a point 20 chains west of the mine entrance, drilling had reached 300 ft. and coal was expected at 350 ft. There is no further mention of this drill-hole.

The report of 1895 stated that the workings were extending in good coal of even thickness to the west and north-west of the dip drive. The


26°
31°
Tender Coal
Old Workings from Adit
Sec. 193
Adit Mouth
13°
15°
13°
Top of Dip
Makarewa River
HOKONUI COLLIERY
Forest Hill S.D.
Scale of Chains
2 1 0 2 4 6
Outcrops of Coal
Outcrops of Measures
192
Bad Coal
To accompany "The Geology of Forest Hill S.D. Southland" by M.V. Rout, 1946.
G.S. 670
G.W.M. 1946.

mine apparently closed suddenly in 1896, and, although the manager, John Hayes, then became Acting Inspector of Mines for the district, no mention of the mine, beyond the fact that it was not working, appeared in the reports of 1897. Hearsay attributes the closing of the mine to flooding from the river, but in view of the fact that the mine was worked underground in 1898, flooding could not have been serious. In all, 50,000 tons of coal were extracted.

The plan of the mine shows that 9 acres of coal were extracted from workings from a dip drive. The pillars were small, most of them being about 15 ft. wide, and few exceeding 30 ft. Progress north appears to have been stopped by "tender coal," progress south by "bad coal." North from the mine entrance the strike curves to the north, indicating that the seam here at the northern end of the basin is folded into a gentle anticline, the axis of which rises to the east.

The mine entrance is only 10 ft. above river-level, and in 1945 was still full of water. The coal at the opening seems to stand well, but parts of the seam appear to deteriorate laterally to shale.

There has been drilling done recently by Mr. Orr, of Wairio, and several of the drill-holes may be seen on the east side of the Makarewa south of the mine. Mr. McDonald, of Tussock Creek, states that many years ago he discovered good coal near the surface north-west of Shark's Tooth Hill, which suggests that the seam may extend this far beneath the river-flats.

Lignite, reported to be of good quality, used to be mined at Tussock Creek. There were at least three seams, one 20 ft. wide. Owing to the steep dip, any reasonable amount cannot be mined open-cast.

The following analyses show that the Hokonui coal is a high-grade lignite, but since in the hand specimen it appears bituminous, and to differentiate from the very different low-grade lignite of Tussock Creek, it has been called sub-bituminous in this report.

The analysis of a sample from the Hokonui mine is compared below with analyses of lignite from Orepuki and coal from Ohai. The analyses of lignite samples from the Tussock Creek workings and from the Mataura Paper Mills pit are also given.

PROXIMATE—(on air-dried coal)

—	Hokonui (1)	Wai-meamea (2)	Moss-bank (3)	Tussock Creek Upper (4)	Tussock Creek Middle (5)	Mataura Paper Mills (6)
Moisture	22.2	22.8	15.5	17.2	22.1	30.4
Volatile matter	39.5	36.8	35.8	34.6	40.8	39.2
Fixed carbon	33.8	36.8	40.9	15.3	32.4	26.3
Ash	4.5	3.6	7.7	32.9	4.7	4.1
Sulphur	0.4	1.2	0.4	0.3	0.5	0.2
Calorific value	9,210	8,760	10,060	5,170	7,820	7,330

All non-coking

ULTIMATE—(calculated to dry-ash free coal)

Carbon	71.6	69.1	74.3	62.7	65.8	66.3
Hydrogen	5.7	5.3	5.3	5.7	4.8	5.2
Nitrogen	1.2	1.1	1.2	1.0	0.8	0.7
Sulphur	0.6	3.6	0.5	0.6	0.7	0.2
Oxygen	20.9	17.7	18.7	30.0	27.9	27.6

(1) Dominion Laboratory memo. dated 25th March, 1946.
(2) Dominion Laboratory memo. dated 11th October, 1945.
(3) Dominion Laboratory memo. dated 21st September, 1945.
(4) Dominion Laboratory memo. dated 25th March, 1946.
(5) Dominion Laboratory memo. dated 25th March, 1946.
(6) Dominion Laboratory memo. dated 18th September, 1945.

OTHER ECONOMIC DEPOSITS.

Limestone of Forest Hill is quarried for agricultural use (report in press by R. W. Willett).

Pebbly Hill gravels have in the past been used for roads.

The clay from Mako clay-pit is quarried and used in McSkimming's brick and pottery works.

REPORT AND ANALYSES BY DOMINION LABORATORY ON MAKO AND PEBBLY HILL CLAYS

——	Mako				Pebbly* Hill
	(1)	(2)	(3)	(4)	(5)
SiO_2	59.63	60.14	60.73	75.92	64.37
Al_2O_3	26.39	26.53	26.12	14.31	19.14
Fe_2O_3	0.81	0.54	0.55	0.77	2.30
TiO_2	1.46	1.29	1.40	1.15	0.75
MgO	0.16	0.18	0.18	0.14	0.86
CaO	0.14	0.14	0.12	0.13	0.00
Na_2O	0.02	0.08	0.06	0.06	0.33
K_2O	0.48	0.65	0.60	0.25	0.98
H_2O+	9.24	9.52	9.25	5.80	9.55
$H_2O-(105°)$	1.55	0.77	0.52	1.13	1.52
	99.88	99.84	99.53	99.66	99.80

(1) Dominion Laboratory report dated 3rd October, 1941.
(2) Dominion Laboratory report dated 3rd October, 1941.
(3) Dominion Laboratory report dated 3rd October, 1941.
(4) Dominion Laboratory report dated 3rd October, 1941.
(5) Dominion Laboratory report dated 6th January, 1943.

*PEBBLY HILL CLAY

PHYSICAL AND BURNING TESTS.—This is a soft, creamy-coloured clay uniform in texture and non-gritty. It is very highly plastic. It moulds well to a very strong raw product. Tempering-water required, 30 per cent. Easily reduced to fine condition.

Results of burning tests made on small tiles made from the clay:—

Dried at 100 °c. ...... Creamy-grey. Linear shrinkage, 6.3 per cent.

Burned at 900 °c. ...... Compact texture. Uniform yellowish-cream. Moderately hard. No sign of vitrification. Linear shrinkage, 7.8 per cent.

Burned at 1,200 °c. ...... Uniform, compact, rich yellow. Excellent shape. Extremely hard, but unvitrified. No cracks or other defects. Linear shrinkage, 12.5 per cent.

Burned at 1,300 °c. ...... Yellowish-brown. Considerable vitrification. Dense compact product of good shape, approaching a stone ware. Linear shrinkage, 12.5 per cent.

Remarks.—This clay cannot be classed as a refractory clay. In view of its uniformity, its softness, exceptionally high plasticity, and behaviour on burning, it may have other ceramic uses. Strong, dense, yellow building-bricks could be made from this clay, and it may have value for the body of sanitary ware and for art pottery. Owing to its colour it cannot be used for pottery generally.

The Dominion Laboratory also gives the following analyses in a report dated 26th June, 1946:—

(6) Tussock Creek: Hanging wall, upper lignite seam; 56 chains at 225° from Trig. C.

(7) Tussock Creek: Foot wall, middle lignite seam; 56 chains at 225° from Trig. C.

(8) Taylor's Gorge: 114 chains at 315° from Trig. F.

(9) Underlying gravel of Pebbly Hill: 482 chains at 80° from Trig. C.

ANALYSES.—The samples, after grinding to completely pass a No. 30 B.S. sieve, were tempered with water and moulded into small test tiles, which were burned at successively higher temperature in an electric furnace and the behaviour noted. The results were :—

—	6	7	8	9
Workability......	Highly plastic. Strong raw product. Rather sticky.	Fair plasticity. Raw product rather weak.	Very soft fairly plastic clay. Low raw strength.	Highly plastic. Strong raw product.
Tempering-Water per cent.	36	28	28	35
Dried at 100°c	Grey - brown. L.S.*, 7.8	Deep yellow -brown. L.S., 6.3	Yellowish-grey. L.S., 8.4	Pale grey. L.S., 9.4
Burned at 870°c......	Rather soft. Uniform pale brick-red. L.S., 7.8	Excellent deep uniform brick-red. Fairly hard. L.S., 6.3	Pinkish-brown. Rather soft. L.S., 7.8	Very pale cream. Rather soft. L.S., 9.4
Burned at 1,000°c......	Fairly hard. Pink red. L.S., 9.4	Excellent deep brick-red. Fairly hard. L.S., 6.3	Pale brick-red. Hard and strong. L.S., 9.4	Coloured as at 870°c. Fairly hard. L.S., 9.4
Burned at 1,100°c......	Steel hard. Pink-brown. L.S., 17.0	Dark red. At transition temperature hard. L.S., 10.9	Dark purple-red. Good deal of vitrification. L.S., 15.6	Pale cream. Hard but not vitrified. L.S., 10.9
Burned at 1,250°c......	—	—	—	Uniform light grey. Well vitrified throughout. L.S., 17.2

*L.S. means per cent. linear shrinkage.

Remarks.—(6) Colour too light a red for brickmaking. No other commercial use.

(7) *An excellent brick clay.*—Optimum burning temperature, about 1,000 °c. Vitrification range appears to be satisfactory, and could probably be extended, if required, by incorporation of, say, 5 per cent. of No. (6). This addition would also improve raw strength.

(8) Colour too light a red for brickmaking. No other commercial value.

(9) This is a clay of considerable promise. In view of its high plasticity good bonding power, light burning colour, and vitrifying properties at high temperatures, it would appear to have possibilities as a *ball clay*. If the quantity available is sufficiently large, I recommend that a reasonably big and representative sample (say, 14 lb.) be sent for trial in sanitary ware to McSkimming and Co., Benhar. If the works trial proved satisfactory, a complete chemical analysis would then be made.

REFERENCES

COX, S. H. (1877): Report on the Geology of the Hokonui Ranges. *Rept. Geol. Expl., No. 11*, 25-48.

McKAY, A. (1877): Notes on Sections and Collections of Fossils obtained in Hokonui District. *Rept. Geol. Expl., No. 11*, 49-90.

MACPHERSON, E. O. (1937): Outline of the Geology of Centre Bush District, Hokonui Survey District, Southland. *N.Z. J. Sci. & Tech., 19*, 194-7.

PARK, J. (1886): Forest Hill Coal Co.'s Coal. *Rept. Geol. Expl., No. 18*, 120-1.

THE HANMER PLAIN AND THE HOPE FAULT

By C. A. COTTON, Victoria University College, Wellington

(*Received for publication, 9th May, 1947*)

Summary

The east-west trending Hope fault, a major dislocation, which has been regarded by some authors as collinear north-eastward with the Kaikoura fault, has its upthrow on the south side. A sunken and sinking area that borders the fault on the north side has become the Hanmer Plain. Along the south side of this there are river terraces with a peculiar history which testify to differential uplift. Up the Hope River there has been movement on the fault in historic and recent prehistoric times; but this latest movement has been locally transcurrent.

THE HANMER PLAIN

THE asymmetric form of the Hanmer basin is a result of differential movements that still continue on a nearly east-west fault along its southern boundary, the Hope fault, as this is best called, for it determines the middle and lower course of the Hope River as well as that of the Hanmer and a reach of the Waiau (Fig. 1) and has been active recently in the valley of the Hope. Along that portion of the fault which forms the boundary of the basin there is a fringe of high river terraces (Fig. 2) that indicate uplift along one bank only of the terrace-making rivers. Along the northern margin of the basin, and indeed around the whole perimeter with the exception of the southern wall, the plain gives place to tapering spurs, not terraced, which descend from the surrounding highland between fan-filled embayments. The spurs narrow to points and plunge beneath the surface of the gravel of the aggraded basin floor (Fig. 3), and this makes it obvious that the floor of the basin has been carried down by a differential movement of depression that seems to be still going on, though no doubt intermittently. It is such sinking that has caused the aggradation of the whole floor of the basin with development of the basin plain; and this downward movement has been in progress, so it appears, while the Leslie Hills block, south of the Hope Fault, has been rising. It is well

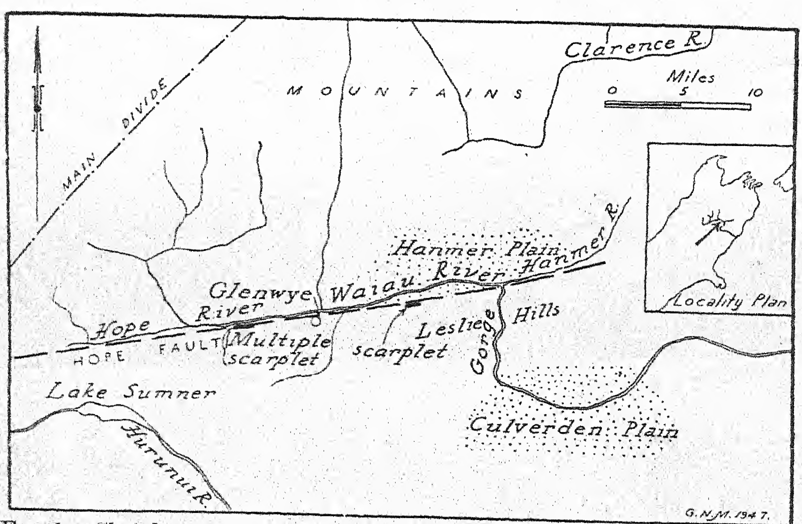


FIG. 1.—Sketch map of part of the Waiau valley system. The inset map shows the locality.

known that the fault which here separates differentially moving areas has been recently active (McKay, 1890, 1892), and, as Speight (1933) has remarked, earth movements on this line have been responsible for producing the majority of the earthquakes that have been felt in Canterbury, including probably the severe Arthur's Pass earthquake of 1929.

As McKay (1892) perceived, the rivers that follow the line of the fault have obliterated much of the evidence of the most recent displacements, and clearly this has long been their habit, but the relation of the straight, terrace-fringed southern wall of the basin to the fault line as a true fault scarp, though one of an unusual configuration, is

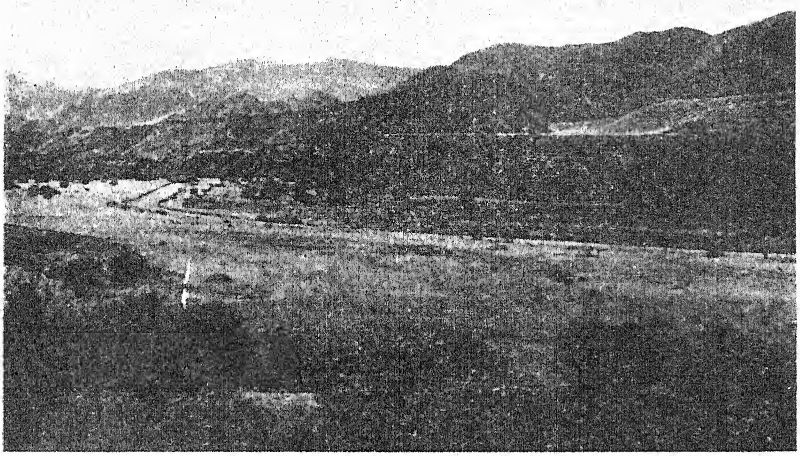


FIG. 2.—Unilateral river terraces bordering the Waiau River along the southern margin of the Hanmer Plain.

FIG. 3.—A maturely dissected fringe of the highland north of the Hanmer Plain is warped down and embayed by alluviation in the basin plain. (Contrast with the southern terraced margin of the basin, Fig. 2).

unquestionable. The lowest terrace is broken, moreover, at the locality indicated in Fig. 1 by a rejuvenating fault scarplet four to six feet high and obviously of recent development (Fig. 4). This was observed by McKay (1892). In places crush zones in the greywacke basement rock are revealed in road cuttings along the Lewis Pass highway where this follows the bank of the Waiau River along the fault line ; but it is not clear whether the crushing resulted from recent faulting or was caused by some more ancient dislocating movement. If the latter, then it appears that the belt of crushed rock has provided a zone of weakness in which recent movements have been localized.

Just below the confluence of the Hanmer and Waiau Rivers the combined stream turns southward and enters a recently rejuvenated antecedent gorge (Figs. 5 and 6) through the Leslie Hills block of country, to emerge again beyond this on the Culverden Plain, which is another and larger tectonic basin of recent development, as Speight (1918) has noted.

Absence of terracing around the Hanmer basin, except on the south side, rules out an alternative suggestion as to its origin, by which I have been previously influenced unduly (Cotton, 1941), that the plain as it exists to-day has been developed by fluvial re-excavation of a gravel-filled basin. The terraces that border the Waiau River in the outlet gorge also indicate that differential movement has been recently in progress. Though high (Fig. 6) and continuous with those fringing the Hanmer Plain at the entrance of the gorge, they converge and become lower downstream and eventually die out in the Culverden Plain, merging there with the alluviated surface. This indicates that the block of country between the basins is not only tilted but is still (intermittently) experiencing a tilt or rotational movement. Up-valley from the Hanmer basin also, terraces emerge at first almost imperceptibly from the plain, become higher up the valleys of the Waiau and Hope, and eventually attain great heights. Here it must be noted that terraces are present on both sides of the valleys, indicating a general tilting upheaval.

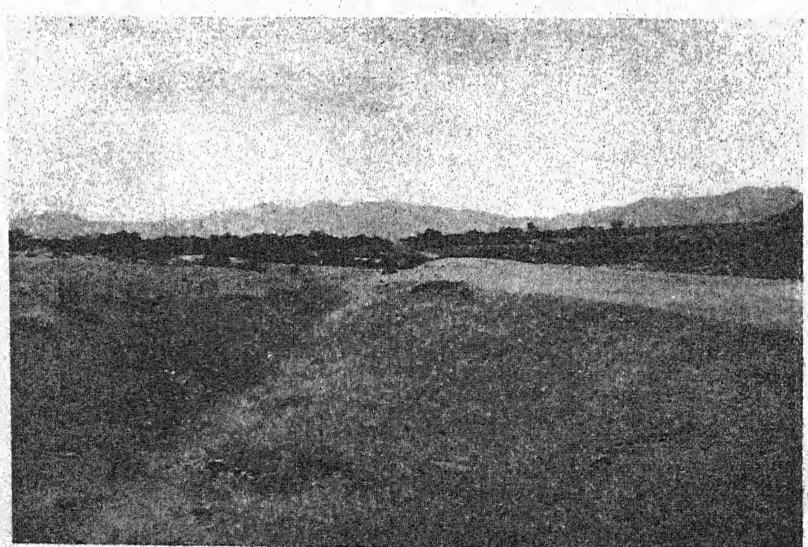


FIG. 4.—Northward-facing fault scarplet on the line of the Hope fault at the locality called by McKay McIntosh's Flat, five miles west of the Waiau outlet gorge.

RECENT ACTIVITY OF THE HOPE FAULT

Evidence of renewal of movement along the line of the Hope fault has been recorded by McKay (1890, 1892) in the Hope Valley. At localities, the one four and the other five-and-a-half miles west of the Waiau River confluence and near the Glynn Wye homestead, he observed two fences on the more or less level surface of a terrace (fully 500ft. above the river and half to three-quarters of a mile back from the edge of the terrace) which had been dislocated 8 ft. and 8 ft. 6 in. respectively by purely horizontal (transcurrent or strike-slip) fault displacement. A photograph of the most easterly of these dislocated fences after it had been repaired (or, in reality, reconstructed) was published by McKay in 1902. Strangely enough the more westerly fence still survives in the form in which it was rebuilt after the dislocation. The photograph of it reproduced as Fig. 7 was taken in February, 1947. Probably the fence was re-aligned, except for the main offset, when reconstructed, thus eliminating any small kinks and departures from the original straight line that were introduced by distributed strike-slip displacement. When McKay made his observations it was known that the lateral movement—dextral according to Anderson's system of nomenclature—had taken place during an earthquake in 1888. A zone of closely spaced parallel cracks, or "rents," as McKay called them, in which strike-slip movement was known, or might be suspected to have taken place at the same time, was traced by McKay for eight miles in the vicinity of Glynn Wye, but was found to pass at each end of this stretch into the beds of the Waiau and Hope Rivers, which had obliterated the "rents."

Though concerned chiefly with the effects and causes of the earthquake of 1888, McKay made passing references also to what he termed an "old line of earthquake rent." This feature is still conspicuous on the high terrace at Glynn Wye and there marks a line of faulting parallel to and northward of that which has recently developed (dislocating the fences). McKay found that both the older and the new

FIG. 5.—Entrance to the rejuvenated antecedent gorge through the Leslie Hills by way of which the outflowing Waiau River drains the Hanmer basin plain. Photo: V. C. Browne

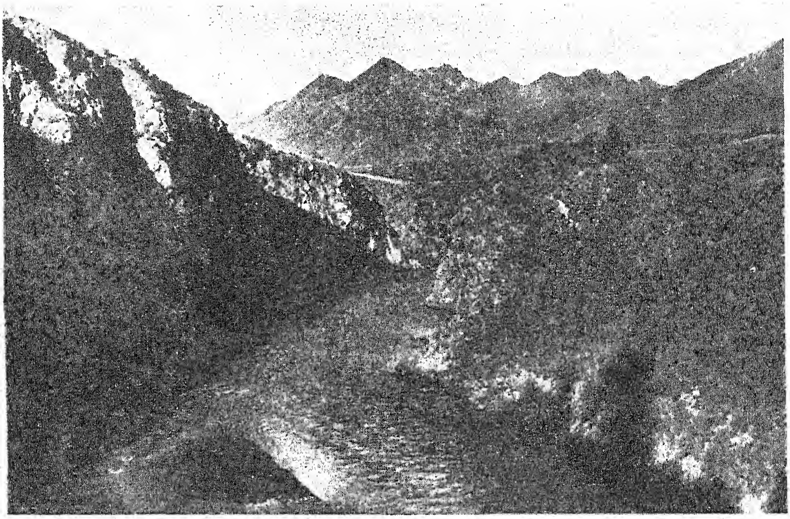


FIG. 6.—Terraces border the Waiau River in the antecedent gorge through the Leslie Hills. Photo: V. C. Browne

breaks could be traced westward from a point about four miles west of the Hanmer-Waiau confluence and extended up-valley for the full length of the east-west reach of the Hope River.

With the exception of the measurable strike-slip displacement at the localities mentioned on the high terrace near Glynn Wye, the traces of the latest earthquake-making disturbance consisted of systems of parallel open cracks in the ground striking east and west with a definite indication of dextral movement at only one other locality. All traces of the "rents" seen by McKay have now been obliterated, but the displacement seems to have petered out in a few miles, and it is scarcely comparable, therefore, with the transcurrent faulting on the San Andreas fault, in California, or that of the Great Glen of Scotland, in both of which cases movement has been of regional extent. Here strike-slip movement seems to have developed locally on a portion of a surface of major dislocation subject elsewhere (and formerly here also) to dip-slip faulting. That this was not the first transcurrent movement locally affecting the Hope fault line is made clear, however, by a cursory inspection of the older cicatrice, or line of "rents," observed but referred to only casually by McKay. Whereas the cicatrice on the same line that has been mentioned earlier as a scarplet of rejuvenation farther east at the base of the scarp facing the Hanmer Plain, seems to have been produced by a movement that was largely or wholly vertical (dip-slip), that on the Glynn Wye terrace presents features of a kind rare or unknown on other New Zealand fault traces which strongly suggest that movement was largely or wholly transcurrent. A broad trench-like form is developed, along which are sag ponds (Fig. 8), and the formerly level terrace tread, which has been deformed, is higher in some places on the north and in other places on the south side of the line, giving an appearance of scissors faulting. In Fig. 7, beyond the offset, the fence line crosses a sagged surface and then ascends a southward-facing scarp or warp at this line which is about 40 ft. high. For miles the whole surface of the terrace is thrown into undulations, as though buckled by lateral movement, so that when walking over it one finds it difficult, but for the gravelly soil underfoot, to believe that the surface is that of a river terrace.

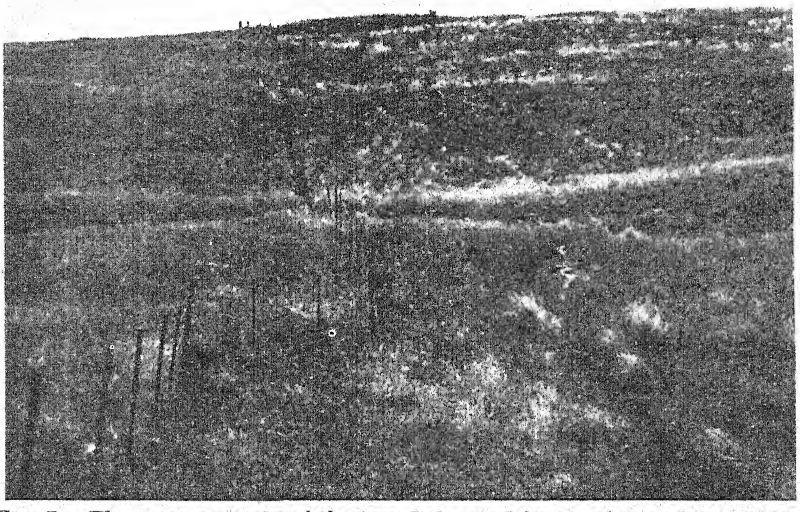


FIG. 7.—The more westerly of the two dislocated fences observed by McKay after the earthquake of 1888 as it is now. View looking north. Beyond the offset in the fence, the fence line crosses an older cicatrice, or trace, of transcurrent faulting. Note the deformation of a formerly level terrace tread.

Immediately east of Glynn Wye the zone of dislocation crosses a valley-side spur, from which landslides have at some time descended to impound a tarn known as Horseshoe Lake in a segment of a valley that has been occupied by a tributary stream (not the Hope River itself as McKay suggested). At Glynn Wye homestead the disturbed ground is on the frontal scarp of the high terrace previously mentioned, while westward it ascends to the tread of this terrace and traverses it for five miles. About four miles from Glynn Wye the disturbed zone approaches the edge, and a very conspicuous multiple scarplet with a total downthrow of about 40 ft. to the north becomes visible from across the Hope valley (Fig. 9). Three separate scarplets composing it are in an equally good state of preservation, and in the case of each of them there is an appearance of a combination of dip- and strike-slip displacement, as has been the case in Japan and Formosa during earthquakes (Heck, 1944). It seems possible that these were all formed during some prehistoric earthquake of very great magnitude; but some scarplets of comparable and less height in the North Island seem to have arisen only as a result of several instalments of movement (Waghorn, 1927; Ongley, 1943). Extensive gullying of shaken and fissured gravels, which has taken place in the downthrown margin of the terrace below the scarplets, may have required for its development, not more than a few decades (centuries at most), since the occurrence of the prehistoric earthquake or earthquakes referred to above.

THE HOPE FAULT IN RELATION TO OTHER MAJOR FAULTS

McKay (1892) regarded the Hope fault as the continuation of another, also recently rejuvenated, which has since been called the Kaikoura fault (1902), as it is along the base of the Seaward Range. Park (1910) and Henderson (1929) have followed him in this, though it has been necessary in adopting the correlation and mapping the faults as one to take a liberty with the topography and

FIG. 8.—Sag pond on the line of faulting marked by buckling or warping of a terrace tread near Glynn Wye. The sag pond is beside the fence dislocation shown in Fig. 7.

place one of the depressed areas shown on Henderson's map (that which is, presumably, the Hanmer Plain) south of the fault, *i.e.* south of the Hope-Waiau-Hanmer river line, instead of in its true position north of it (Fig. 1).

McKay did not resort to the device of moving the Hanmer Plain southward, but he was at some pains, though almost apologetically, to explain that the basin containing it, which lies admittedly north of the fault, may be "to a large extent" of erosional origin, whereas it it is clear that his keen eye and his reason, or intuition, had already assured him that it was a downthrown or downwarped tectonic feature. He suggested the hypothesis of erosional origin evidently as a concession to a ruling theory of southward downthrow on a Kaikoura-Hope fault; but he also expressed the opinion that relatively low summit altitudes in the mountains north of the Hope, where the main divide is now crossed by the Lewis Pass highway and where there are other low passes, might indicate a northerly downthrow in that area. Thus a theory of cross faults which he advanced to account for possible change of downthrow from north to south in a short distance may be in part correct. Alternatively, however, it may be true that the throw changes scissors-fashion. No doubt there is much subsidiary warping; there are certainly bifurcating faults and perhaps there is some cross faulting; but to rely entirely on a theory of mashing of the terrain into small blocks would be inconsistent with acceptance of McKay's valuable conception of major faults in this region.

The Hope fault itself is undoubtedly a major dislocation, whether or not it is one and the same with the Kaikoura fault, but only at the Hanmer basin is there clear evidence that a large differential displacement with downthrow to the north has been in progress very recently on this line. If, as seems possible, the Hope fault, with downthrow generally to the north, is not collinear with the Kaikoura fault but intersects it, is intersected by it, or meets it at an angle, the Hanmer basin, or the larger depression of which the basin is a part, may perhaps correctly be regarded as continuous with a still larger complex depression farther north which contains the valleys of the Upper Clarence and Awatere Rivers.

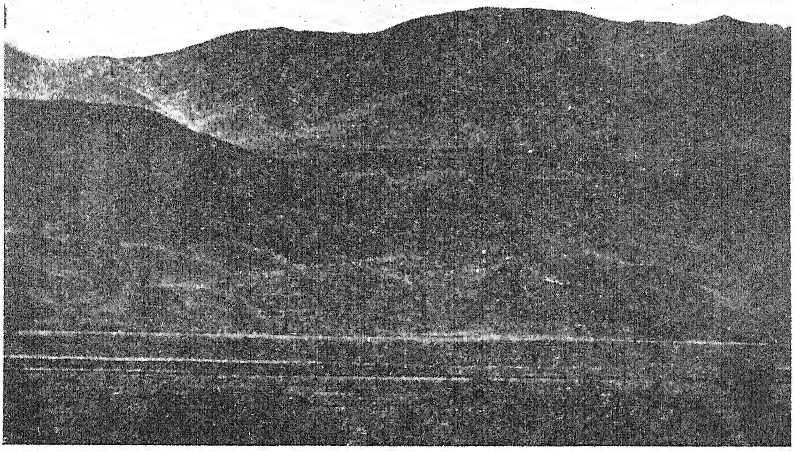


FIG. 9.—Multiple scarplet near the edge of a high terrace on the south side of the Hope River west of Glynn Wye.

On the other hand, a hypothesis that reversal of the direction of of downthrow takes place at some time during the histories of some great faults may bring into line with the topographic facts the theory that the Hope and Kaikoura faults are one. Probably the best explanation that can be offered of the remarkable reverse scarplets that are to be found in New Zealand along the bases of some maturely worn fault or fault-line tectonic scarps is afforded by the hypothesis that ancient faulting has gone into reverse in a new faulting that has just begun (Cotton, 1947) and in this case such reversal may have taken place earlier.

REFERENCES

COTTON, C. A. (1941): "Landscape," p. 271. Cambridge.

———— Revival of Major Faulting in New Zealand. *Geol. Mag.*, *81*, 79-88.

HECK, N. H. (1944): Japanese Earthquakes. *Bull. Seis. Soc. Am*, *34*, 3.

HENDERSON, J. (1929): The Faults and Geological Structure of New Zealand. *N.Z. J. Sci. and Tech.*, *XI*, 93-7, map.

MCKAY, A. (1890): On the Earthquakes of September, 1888, in the Amuri and Marlborough Districts of the South Island. *Rept. Geol. Explor.*, *20*, 1-16.

———— (1892): The Geology of Marlborough and South-East Nelson. *Rept. Geol. Explor.*, *21*, 1-28, maps.

———— (1902): "Report on the recent seismic disturbances within Cheviot county, in Northern Canterbury, and the Amuri district of Nelson, New Zealand (November and December, 1901)." Wellington.

ONGLEY, M. (1943): Surface Trace of the 1855 Earthquake. *Trans. Roy. Soc. N.Z.*, *73*, 80-9.

PARK, J. (1910): "Geology of New Zealand," p. 262. Christchurch.

SPEIGHT, R. (1918): Structure and Glacial Features of the Hurunui Valley. *Trans. N.Z. Inst.*, *50*, 93-105.

———— (1933): The Arthur's Pass Earthquake of 9th March, 1929. *N.Z. J. Sci. and Tech.*, *XV*, 173-82.

WAGHORN, R. J. (1927): "Earthquake Rents" as Evidence of Surface Faulting in Hawke's Bay. *N.Z. J. Sci. and Tech.*, *IX*, 22-6.

INCLUSIONS OF IGNEOUS AND METAMORPHIC ROCKS IN THE SERPENTINITE AT HARPER'S, NEAR WELLSFORD, NORTH AUCKLAND

By J. A. BARTRUM, Auckland University College

(*Received for publication, 12th May, 1947*)

Summary

Description of rocks derived from a serpentinite mass; these include not only troctolites and other common associates of serpentinites, but also, amongst others, rocks such as schists, which represent part of a widespread, deep-seated metamorphic basement, and coarse-textured dolerite with pigeonite as one of its pyroxenes.

INTRODUCTION

EXTENSIVE recent quarrying, mainly in the Silverdale-Kaukapakapa-Wellsford area, of relatively small lenses of serpentinite for use in the manufacture of serpentine-superphosphate has led to the discovery of a number of interesting types of rocks. Many of these already have been described by Bartrum (1944) in a recent paper, but later discoveries at Harper's, on the northern highway about a mile south of Wellsford, deserve record. The rocks concerned were collected from a large dump and were not located *in situ*, so that their relationships to the serpentinite with which they occur can only be surmised; it was impracticable to keep the various excavations under close geological observation. Most of the rocks have been included in the serpentinite as a result of earth movements. Amongst other interesting types, they include amphibole schists and other metamorphic rocks, which, however, are dissimilar from schist recorded by Turner and Bartrum (1929, p. 898) from serpentinite about two miles south of Silverdale. Various troctolites and dolerites amongst the rocks at Harper's almost certainly are connected genetically with the serpentinite, for these rocks have been recorded from adjacent serpentinite areas by Bartrum (1924; 1944), Turner and Bartrum (1929), and Ferrar (1934) along with anorthosite, various gabbros, and other consanguineous rocks. In addition to sediments, the following types of rock have been found at Harper's: serpentinites, a granodiorite, diorites, an epidiorite, metamorphosed anorthositic gabbros, two dolerites (one with pigeonite), schists, and various basic lavas.

DESCRIPTION OF ROCKS

(1) *Serpentinites*

On the whole, the serpentinites at Harper's show little variety in thin section, in spite of considerable variation in colour and texture in hand specimen, often largely in consequence of earth movements, by which they have been shattered and at times converted locally into autoclastic breccias. Their parent rock essentially has approximated to dunite, through bastite in small amount nearly always accompanies the mesh-structure serpentine that has been derived from the original olivine; locally the bastite may be concentrated in phases that represent earlier harzburgite. The amount of iron-ore that was freed during serpentinization of the olivine varies considerably; picotite generally is present in large irregular sporadic crystals, while chromite is rare.

(2) "*Second Generation*" *Serpentinite*

A puzzling feature shown by many of the North Auckland masses of serpentinite, in particular by those at Harper's, is the occurrence of what, for purposes of distinction, may be called "second generation" serpentinite. This is usually a fairly hard, dense, dark-greenish-black material with wax-like lustre, though occasionally it is greenish-yellow in tint. It commonly forms compact veins seldom over an inch in width which occupy fissures, but at times it is highly spongy in nature, weathering where actually exposed at the surface to a honeycombed mass with whitish exterior studded by small octahedrons of magnetite up to 1.5 mm. across. A few feet below this spongy surface material one can occasionally find lobate veins of the dark wax-like phase ramifying irregularly in soft earthy-looking pale-greenish-white serpentinite. Possibly the superficial sponginess results from the selective removal of this latter material.

This "second generation" serpentinite has not so far been found to extend downwards beyond a few feet from the surface.

Thin sections were prepared of the contact of the dark with the pale-green serpentinite and of other phases of this unusual material. One made from a dark variety shows freely what appears under ordinary light to be vermicular structure, but which under crossed nicols resembles flattened meshes of chrysotile derived from olivine. Much of the general matrix of the rock, however, is more or less structureless, though probably granulated, serpentine; it has small patches of carbonate and widely scattered octahedrons of magnetite up to 1mm. across. The thin section of a pale-yellowish-green variety of this material shows no recognizable structure; its magnetite is in numerous tiny octahedrons and there are rare large crystals of chromite. The material of the dark lobate vein and of its host do not contrast in section as they do in hand specimen; while the dark phase is very-pale-brown in tint and shows strongly what appears in ordinary light to be sub-equal grains about 0.1 mm. in diameter, the other is colourless and only faintly shows this pseudogranularity (Fig. 1), which actually is mesh structure, with the borders of each "grain" determined by minute veins of transversely fibrous ferriferous chrysotile and the serpentine within very poorly birefringent and irregularly fibrous. Scattered octahedrons of magnetite characterize both light- and dark-coloured phases.

The origin of this "second generation" serpentinite is uncertain. Its location only in or bordering superficial fissures appears to preclude the possibility of its being a product of autometamorphism, whereby Hess (1933) in an important study explains the serpentinization of peridotites and the concomitant formation of veins of chrysotile-asbestos as a result of the work of somewhat acidic residual liquids remaining in the mesh of the ultrabasic rock after its crystallization. Hess insists that this is quite distinct from later hydrothermal alteration; in the rocks that he described this latter produced what he has called "steatitization," which is marked by a characteristic hornblende, actinolite, chlorite, talc, carbonate series due to acidic solutions which often appear to have arisen from nearby younger acidic intrusions.

Information based on magnetometer surveys and on close grids of bores and kindly made available to the writer by Messrs. J. Healy and C. A. Fleming, of the New Zealand Geological Survey, suggests

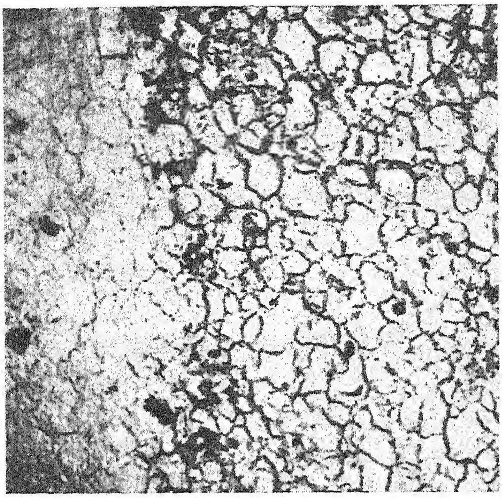


FIG. 1.—"Second generation" serpentinite. Dark, hard phase (right) invading greenish-white soft serpentinite (left). The small opaque mineral is magnetite. (× 42).

forcibly that the numerous serpentinite bodies near Silverdale and Wellsford are small, shallow lenses which are enclosed in soft sediments of late Cretaceous to mid-Eocene age and which have been disrupted from a few large earlier intrusions and transferred to their present locations by earth movements. It is most improbable that, during this process, they have preserved their original attitude and it is impossible, therefore, to regard the veins of "second generation" serpentinite as derived either by autometamorphism or by hydrothermal action, for, if so, they must have been formed prior to the dismemberment of the original ultrabasic intrusions and cannot have maintained or attained in all cases the purely superficial location that they invariably possess in the displaced lenses of serpentinite.

The conclusion emerges, therefore, that this "second generation" serpentinite represents normal serpentinite which has been altered by downwards-moving surface waters. It differs from the normal rock partly in details of any mesh structure that it may show, but more importantly in its possession of isolated well-shaped octahedrons of magnetite. In the local normal serpentinites this mineral is invariably in irregular strings of granules such as characteristically arise during the serpentinization of olivine. Current belief is strongly against the possibility of low-temperature formation of magnetite, yet, unless such possibility exists, the origin of the "second generation" serpentinite that has been described remains an insoluble paradox.

(3) *Granodiorite*

Granodiorite is represented by rare crumbly blocks up to 9 in. across which show fairly prominent small dark patches of ferromagnesian mineral and superficially appear to be considerably weathered. The thin section (No. 19) shows that the rock is a considerably crushed type largely of plagioclase (approximately An_{28}) with probably about 20 per cent. of quartz, though granulation has affected this latter rather than the feldspar, so that it is hard to estimate its proportions. There is about 5 per cent. of biotite in small wisps which have been converted in very large part to chlorite.

(4) *Diorites* (Fig. 2)

Diorites are represented by thin sections Nos. 1, 6, 21, and 26, and are all very much alike, except that No. 26 is much coarser in grain than the others. The ferromagnesian mineral is a grass-green hornblende which varies in amount from about 35 per cent. to 45 per cent. with, in No. 26, the addition of a little reddish-brown biotite, which has been replaced to a considerable extent by chlorite with a little epidote and iron-ore. The chlorite is mainly the usual green variety, but there is also what is taken to be a pale-reddish-brown member of this group of minerals. Apatite and iron-ore are occasional accessories. The feldspar generally is very largely replaced by kaolinite and sericite and rarely shows more than ghosts of albite twins. In No. 26 it is near andesine-labradorite.

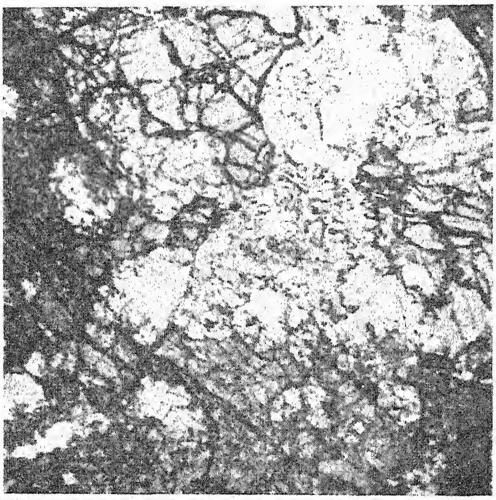


FIG. 2.—Diorite (No. 6), showing green hornblende and weathered plagioclase. (× 42).

In No. 1 there are irregular lensoid veins of plagioclase up to 2 in. in maximum width which represent pegmatitic invasions. In a thin section cut to show the contact between diorite and pegmatite, right at the contact there is a vein 3mm. in width composed almost wholly of almost colourless granulated epidote. The crystals of feldspar in the pegmatite may be as much as 5mm. across, but are so clouded by "kaolin" that exact determination of their variety proved impracticable, though this latter is near basic andesine. Locally there is slight granulation of this mineral. The pegmatite also contains a very little coarse sphene, a little poorly ferriferous epidote, and about 7 per cent. of interstitial finely granulated monoclinic pyroxene, and, near the contact with the diorite, blades of actinolitic amphibole tend to enter its plagioclase.

(5) *Biotite Diorite Porphyry* (= *Biotite Porphyrite*) (Fig. 3)

This rock (No. 24) has numerous somewhat rounded phenocrysts of plagioclase from 0.5 mm. to 1 mm. across set in a fairly coarsely granular matrix of plagioclase with about 10 per cent. of pale-brown

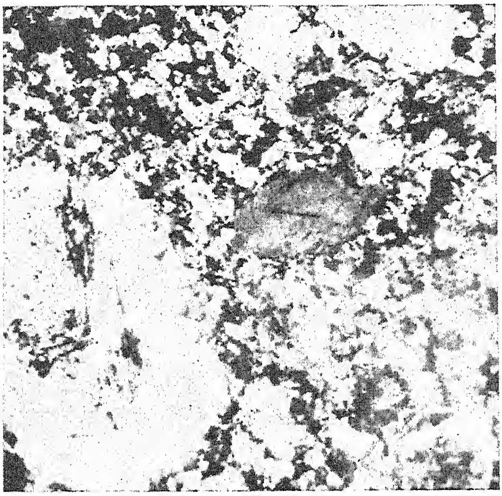


FIG. 3.—Diorite porphyry (= porphyrite) (No. 24), showing rounded anhedral phenocrysts of plagioclase (one enclosing shreds of biotite) in granular feldspathic groundmass. Nicols crossed. (× 42).

biotite which is now mainly almost colourless green chlorite in small shreds. Zircon and apatite occur in small quantity along with sporadic coarse sphene. The phenocrysts of plagioclase are rarely twinned, but almost universally show zonal growth ; they are somewhat kaolinized and at times have given rise to a little iron-poor epidote. Their variety is approximately oligoclase-andesine. A small vein of zeolite was also noted.

(6) *Epidiorite*

This is a medium-grained sub-ophitic rock (No. 3) with basic labradorite and brownish-green uralite in subequal amount, needles of apatite in fair number, and about 8 per cent. of coarse iron-ore (? magnetite). The uralite includes small remnants of the original diopsidic pyroxene. Epidiorites have been recorded from several localities in the Orewa basin, a little over twenty miles to the south-south-east of Harper's (Turner and Bartrum, 1929, p. 897), and probably are connected genetically with the serpentinites.

(7) *Gabbros*

(a) *Troctolite.*—Troctolites have been found freely associated with the North Auckland serpentinites (Bartrum, 1944), though usually considerably altered. The present example (No. 40) is unusual in the relative freshness of its olivine and feldspar and in the presence of a few flakes of a colourless mica which probably is bleached biotite, such as is believed to occur also in rocks described later in this paper. About 15 per cent. of olivine occurs usually in isolated crystals not over 0.5 mm. in diameter, but locally is aggregated into masses 3mm. or more across. It commonly is fringed by about 8 per cent. of an almost colourless monoclinic pyroxene which has ophitic relations to the feldspar. The larger crystals of olivine show considerable unaltered cores (Fig. 4), but otherwise there has been conversion to chrysotile in the early main cracks, while within the mesh so formed there is a highly birefringent pale - yellowish - brown or pale - greenish - brown secondary mineral, near bowlingite in its properties, which occasionally

is accompanied by a little bluish-green chlorite and a little carbonate (? magnesite). The plagioclase is a basic variety near bytownite and is often considerably kaolinized.

(b) *Altered Gabbros.*—There are included here an altered troctolite and another group of altered gabbros which differ materially from the first, although similar in most respects one to another.

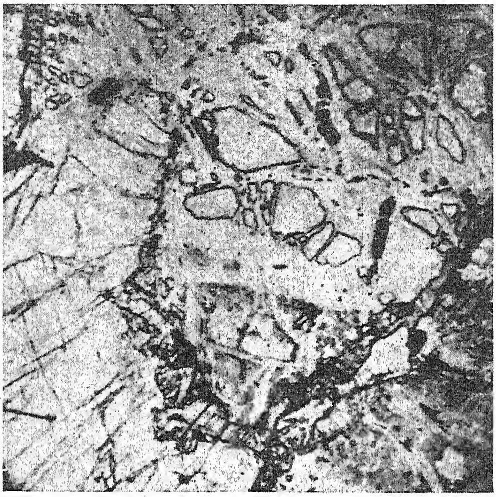


FIG. 4.—Troctolite (No. 40). Plagioclase to the left ; to the right a large mass of olivine largely converted to serpentine and enwrapped below by augite. (× 42).

In the troctolite (No. 9) almost all of the original minerals are replaced by alteration products. Olivine is represented by numerous rounded pseudomorphs of serpentine which do not often exceed 1mm. in diameter. The serpentine usually is a very pale, almost colourless, variety which shows the usual mesh structure and may be accompanied by strings of iron-ore. There are a little bastite, some of which has carbonate included between its cleavage planes, and rare picotite and chromite. The balance of the rock almost certainly originally was feldspar, but it is now coarse abundant aggregates of carbonate (? magnesite) which are enclosed in fine-grained general matrix which is in far less amount than the pseudomorphous serpentine. This matrix includes small grains of carbonate in small number and as a rule abundant chlorite ; there appears, however, to be also an undetermined mineral with a few tiny prisms of zoisite.

A bluish-green chloritic mineral is not infrequent in flakes which occasionally are as much as 1.5 mm. in length. On account of the fact that some of its shreds showed abnormally high birefringence, the writer sent the thin section of the rock to Dr. C. O. Hutton, of Otago University, who assures him* that the mineral is one of the common chlorites, " possibly a negative penninite." It is obviously pseudomorphous after biotite, for rare small deep-brown shreds of this mineral persist. Its local high birefringence probably is due to unreplaced biotite, for in other parts of the thin section there are occasional flakes of a colourless mica which is believed to be bleached biotite.

*Personal communication.

In the main group of altered gabbros (Nos. 5, 11, 43, 44) the original ferromagnesian mineral has been changed by dynamic or regional metamorphism to a pale-green, almost colourless, actinolitic amphibole, while accompanying biotite has been transformed to chlorite. A constant and interesting feature is the crystallization of numerous needles of an amphibole of the actinolite-tremolite series within the boundaries of what were once, if not now, large crystals of plagioclase. Sometimes the needles lie apparently with haphazard disposition, but more often they are in parallel series which follow the planes of cleavage (Fig. 5). Dr. C. O. Hutton, of Otago University, who examined some

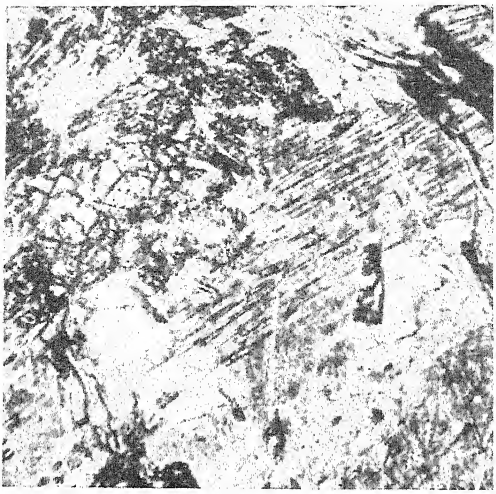


FIG. 5.—Metamorphosed gabbro (No. 11). In south-east half, altered plagioclase enclosing needles of actinolite which are in parallel series above and haphazardly arranged below. Refractive material at upper left is actinolite. (× 42).

of the thin sections concerned, notes* that Rosenbusch (1907, p. 380) records similar permeation by needles of smaragdite and epidote of the feldspar of a crushed gabbro that had suffered extensive mineralogical re-arrangement, and that he himself (Hutton, 1936, pp. 30-1) has described comparable development of chlorite and actinolite in the fissures of the feldspar of a granulated pegmatitic secretion which was found as a boulder at Lake Wakatipu*. In the present instance it is noteworthy that, in spite of the rocks having been affected by low-grade dynamic or regional metamorphism, their feldspar fails to show any significant granulation, bending, or development of the indefinite twinning lamellae that so commonly appear in cataclastically affected feldspars.

Rocks Nos. 5, 11, and 44 are closely similar one to another and probably come from the one parent intrusion; macroscopically they closely resemble local serpentinized troctolites, for they appear in hand specimen to be coarse whitish feldspathic rocks blotched by green of various shades. In thin section the feldspar of No. 11 is seen to be replaced by small irregular crystals of a mineral which kindly was identified by Dr. C. O. Hutton, of Otago University, as a zeolite which he suggests may be laumontite or mesotype, though precise tests have not been applied. This zeolite also forms fairly wide veins with its

*Personal communication.

crystals roughly transverse to the veins. In other such veins there may be analcite in considerable amount along with zeolite, while a little of the former mineral also occurs elsewhere in the rock. Feldspar (basic labradorite) that is unreplaced tends to be aggregated in crystals about 1mm. across, and, in addition to needles of amphibole, is penetrated by irregularly directed veinlets of zeolite ; in rare cases it shows slight bending of its twinning lamellae. The fact that the veins of zeolite transect the general rock fabric shows clearly that the zeolitization has followed cataclastic metamorphism of the original gabbro.

In No. 5 the feldspar is unaltered but for local generally inextensive sericitization, but in No. 44 only insignficant remnants of this mineral survive in a dense matte of alteration products which the writer was unable to identify with certainty. A little sericite is present, and what appears to be prehnite in fairly large amount, as well as tiny scales of a mineral which, from its low refractive index and low birefringence, is likely to be a zeolite. In some of the rocks a clinozoistic epidote mineral may be present in moderate amount as a derivative of the feldspar.

Feldspar or material replacing it comprises about 70 per cent. of the gabbros described in this section; with it there is about 15 per cent. of a very-pale-green actinolitic amphibole which usually is in characteristic bladed crystals. Almost colourless chlorite which apparently is pseudomorphous after biotite is fairly plentiful, especially in No. 44, where there is at least 15 per cent. of it associated, as in others of these rocks, with very small granules and narrow prismatic crystals of a dark-brown highly refractive mineral which appears to be zoisite or closely allied member of the epidote group of minerals. The chlorite masses may include flakes of a white mica which is believed to be bleached biotite and is especially plentiful in No. 11 (*a*). Iron-ores and other usual accessory minerals are practically absent. In one or two thin sections talc occurs amongst the secondary minerals, particularly in No. 11, where also there are occasional patches of deep-green serpentine which probably is pseudomorphous after olivine.

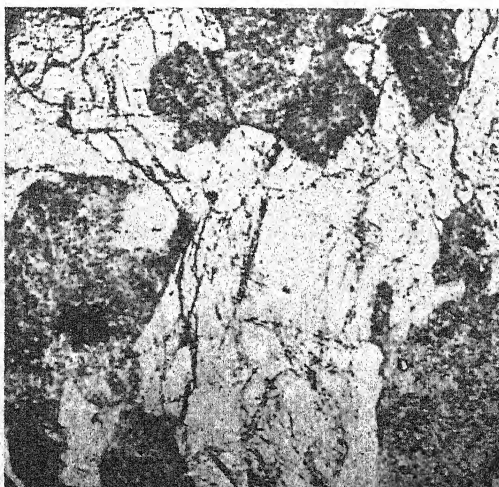


FIG. 6.—Altered ? troctolite (No. 43). The darkly clouded areas are prehnite, the whitish ones actinolite. (× 42).

Rock No. 43 was found as a block about 18 in. in average dimension ; parts of it are relatively leucocratic and more or less resemble local altered troctolites, but the main mass is dark and is seen in thin section to consist of actinolite (about 60 per cent.) and of a mineral clouded by decomposition products which is taken to be prehnite (Fig. 6), and has the same optical properties as a similar mineral recorded by Bartrum (1944, pp. 29 and 32) in troctolites elsewhere in this northern region, though it is in much larger crystals. Small grains of zircon are not infrequent and veinlets of serpentine traverse the rock.

The leucocratic phase of the rock has about 15 per cent. of actinolite along with a subequal amount of very-pale-greenish-brown chlorite in fairly large flakes which appear to be pseudomorphous after biotite. There is crude parallelism of elongated crystals both of chlorite and actinolite (Fig. 7).

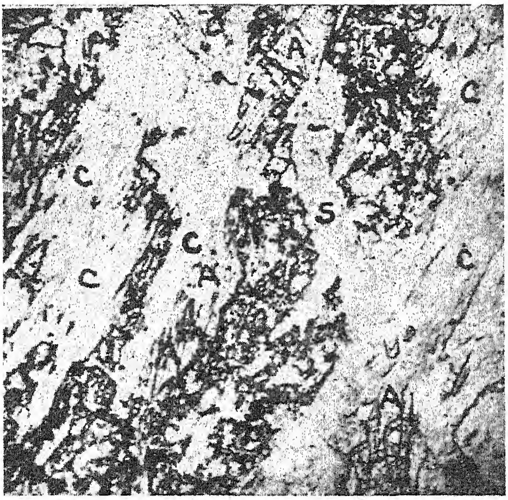


FIG. 7.—Leucocratic phase of the rock of Fig. 6. Local sub-parallelism of actinolite (A) and chlorite (C). Speckled dark material is altered plagioclase ; S is a vein of serpentine. (× 42).

The feldspar of the now-metamorphosed gabbro that this rock undoubtedly represents is now a mixture of several minerals. Prehnite is in considerable quantity both in veins and widespread along with what appears to be the same zeolite as in rock No. 11, locally abundant chlorite in tiny shreds, and a small quantity of a clinozoisitic epidote.

According to Harker (1932), serpentinization and development of amphibole from ultrabasic and associated rocks are characteristic products of low-grade regional metamorphism. On account of the frequent saussuritization of the feldspar of troctolites enclosed in many of the serpentinites of North Auckland, with the production particularly of prehnite and zoisitic epidote, the writer has been inclined to believe that serpentinization has been effected by volatile constituents arising during the late-magmatic stage of injection. This is contrary to the view of Hess (1933) and others, who ascribe it to autometamorphism, or alteration by interstitial residual liquids.

The altered gabbroid rocks now described seem definitely to be the product of dynamic or low-grade regional metamorphism, particularly as some degree of parallelism of elongated minerals is shown

by one of them (No. 43). Subsequent to the formation of actinolite from earlier ferromagnesian material there has been, however, the passage through the rocks of the fluids that caused the zeolitization that is so well shown in No. 11.

In view of the association locally, as is commonly the case elsewhere, of troctolites and other gabbros with the serpentinites, it is illogical to postulate that the present regionally metamorphosed gabbroid rocks were other than substantially contemporaneous with the first-named unaltered rocks. If so, it is necessary to consider how one group of rocks could have been regionally metamorphosed while other coeval similar rocks remained unaltered. The regional metamorphism almost certainly was accomplished during folding and thrusting movements which, as noted earlier in this paper, have disrupted larger ultrabasic intrusions into discrete small lenses which have been carried from their parent mass until to-day they freely spot the weak late Cretaceous or earlier Tertiary sediments by which they are enclosed. These orogenic movements probably were a late phase of those which, on analogy elsewhere (Benson, 1926), favoured the intrusion of the ultrabasic masses and their associates. All change that these rocks have suffered since their injection, whether it be serpentinization, zeolitization, development of actinolite, or other alteration, must have taken place prior to emplacement of their masses in their present locations; the uniform serpentinization that is demonstrated, for example, could not have been effected upon a host of fairly widely separated small bodies.

It is suggested, therefore, that subsequent to serpentinization, whether the latter was by volatile constituents escaping upwards from subjacent magma or by autometamorphism, acute compressive movements came into operation, but were unable to build up noteworthy stress in the weak incompetent late Cretaceous and early Tertiary sediments of the region except where they were invaded by major basic intrusions. It is believed that fluids that had arisen from the magma that was crystallizing below had already serpentinized the peridotites and that these latter were thereby rendered sufficiently incompetent to protect small enclosed gabbroid intrusions from the incidence of severe stress, so that the rocks of these latter would fail to show the actinolitization that characterizes the altered gabbros that have been described. Zeolitization, which has been shown above to have followed regional metamorphism, must also have occurred before the parent intrusions represented by these altered rocks were dismembered by the orogeny.

Although the matter must remain in doubt, the writer believes that in some of his altered gabbros the amphibole has been derived from earlier pyroxene and in others from olivine. For example, No. 5 is likely to have been a normal gabbro with the usual pyroxene, for its feldspars are almost unaltered and in this respect contrast with those usual, though not invariable, in the local troctolites. In No. 11 the presence of earlier olivine is indicated by occasional pseudomorphs of serpentine; this fact suggests that actinolitization of pyroxene here followed serpentinization of olivine, for one could not expect differential treatment of the original olivine whereby some of it was converted to serpentine, though most of its crystals were changed to actinolite. The remaining rocks (Nos. 43, 44) of this group, however, probably represent earlier troctolites in which the olivine has been

metamorphosed to amphibole, for in favour of this suggestion is the fact that the writer has found other troctolites (Bartrum, 1944) in which needles of actinolite occur in small number within the boundaries of crystals of serpentinized olivine, while co-existing diallage is unaffected. Dr. C. O. Hutton has mentioned to the writer* that Finlayson (1909, pp. 374-5) has recorded the derivation of New Zealand nephrite from olivine, while Flett and Hill (1912, p. 71) have suggested that the tremolite of certain rocks that they described may in part have been developed from olivine. In addition, H. H. Read (1931) has described the production of tremolite from olivine in manner similar to what is seen in occasional North Auckland troctolites.

(8) *Dolerites*

A dolerite represented by rocks Nos. 16 and 17 is a coarse-grained type with from 16 per cent. to over 30 per cent. of titaniferous augite in stout, somewhat euhedral crystals, generally from 0.5 mm. to 1 mm. in length, which have sub-ophitic and poikilitic relations to the feldspar (basic labradorite), which is the main constituent of the rock and is in lath-shaped crystals which seldom exceed 0.7 mm. in length (Fig. 8).

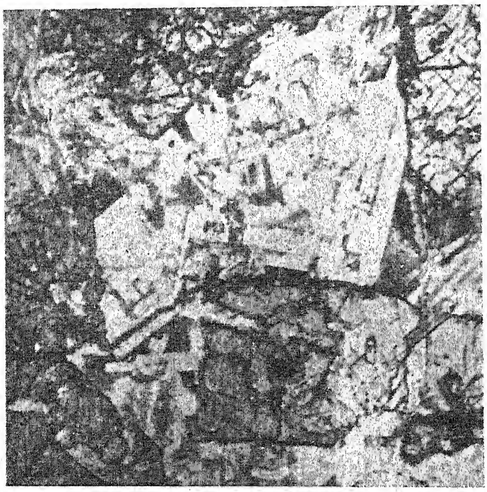


FIG. 8.—Dolerite (No. 16). Sub-euhedral titaniferous augite in a coarse matrix of laths of plagioclase with chlorite (pale-gray) in the interstices. (× 42).

The augite encloses small grains of brown hornblende, by which it is occasionally outgrown terminally, though more often its crystals have a limited extension of fibrous greyish-brown uralitic amphibole. There are sporadic large irregular crystals of iron-ore (? ilmenite) and, in one rock, needles of apatite are numerous, though infrequent in the other. About 15 per cent. of green chlorite occupies the interstices between laths of feldspar as well as being dispersed within these latter. A bluish-green chlorite, which occurs perhaps to the extent of 6 per cent., appears at times to have been derived from earlier amphibole ; its main source, however, has been reddish-brown biotite of which a few small remnants survive. One or two pseudomorphs of green chlorite have form and fracture that suggest original olivine.

*Personal communication.

Thin sections Nos. 2 and 29 are of altered, strongly ophitic, coarse-grained olivine dolerite which is of particular interest in that its almost colourless pyroxene includes pigeonite and subcalcic augite in addition to augite. Locally the pyroxene may be aggregated to exceed 40 per cent. of the bulk of the rock, though elsewhere it may be scarce. A little brown biotite is present, but chloritic replacements of it are abundant, especially in parts of the rock where the content of pyroxene is reduced. Greenish-brown hornblende also is not uncommon, while there are occasional crystals of titaniferous iron-ore with which granules of sphene are associated, while rare isolated large wedge-shaped crystals of this latter were noted in No. 2. Long needles of apatite are plentiful on No. 29, but scarce in No. 2. The olivine has been relatively plentiful (? 10 per cent.) and tends to be aggregated, often with chloritic replacements of biotite, in parts of the rocks in which there is a reduced proportion of pyroxene. It has been in somewhat small irregular crystals, now converted wholly to talc, iron-ore, and usually a little green chlorite. This last mineral is fairly freely distributed even where not obviously derived from biotite. The pyroxene not uncommonly is fringed by the same type of uralitic amphibole as was noted in the earlier-described dolerites, especially No. 2.

Much of the plagioclase (basic labradorite) has been replaced by various products. Particularly in No. 29 there is abundance of a brown, often poorly translucent, almost isotropic material with much lower refractive index than Canada balsam; this probably is a zeolite, for undoubted zeolite is distributed widely with scales of chlorite and also constitutes transecting veinlets in No. 29. There is also a mineral in very finely crystalline state which is general in No. 2, although less so in the other thin section, and may vary from deeply clouded to transparent; it is possibly kaolinite.

The determination of pigeonite and subcalcic augite very kindly has been made, on the writer's suspicion of its presence, by Dr. C. O. Hutton, of Otago University, who obtained the following values for 2V on the universal stage in sodium light (this latter because of strong dispersion in the pyroxene): 42°; 46°; 45°; 46°; 46°; 41°; 19°; 40°; 50°; 45°; 21°; 44°. He states also* that the birefringence determined by means of the Berek compensator is 0.025 (plus or minus 0.003) and that the angle Z to c by the method of Nemoto (1938) is 43°.

Recently Benson (1944, pp. 111-8) has made a survey of the literature of pigeonite, and accepts the view of Barth, Hess, and others that this pyroxene occurs only in the quickly cooled rocks, although he favours the suggestion that the cause may depend rather on the content of volatile constituents in the magma than on the rate of cooling. The present writer (Bartrum, 1944, p. 33) already has recorded the occurrence of pigeonite along with augite and a little hypersthene in an olivine gabbro which is associated in its area of occurrence with North Auckland serpentinites. The present recognition of pigeonite and subcalcic augite in a dolerite adds further demonstration that these pyroxenes are not restricted to the quickly cooled rocks and perhaps supports the suggestion noted above that the factor that determines their crystallization may be the content of volatile constituents in the crystallizing magma.

*Letter of 15-3-47.

(9) *Basic Lavas and Intermediate Igneous Rocks*

Altered basic lavas and other, sometimes indeterminate, igneous rocks occur among the blocks found at the dump at Harper's, Wellsford, but have been given only casual attention. Those sectioned include one which is almost wholly opalized and others with abundant amygdules of calcite which have their counterparts farther south in blocks at the foreshore at Orewa Bridge, on the northern highway (Turner and Bartrum, 1929, p. 898). No. 42 appears to represent a crushed ophitic aphyric coarse-grained basaltic lava with nests of uncrushed rock set in a granulated matrix. It has a relatively large amount of dark-brown, almost opaque, chloritic material dusted by tiny specks of iron-ore, which occurs interstitially between laths of plagioclase ; this may be taken to be a phase of palagonite.

No. 41 is a feldspathic igneous rock which the writer was unable to classify and which has been so crushed that only a few crystals of greatly kaolinized feldspar some 3mm. across survive as " eyes " in the general finely granulated matrix. There are numerous broken crystals of augite, which generally are very small, but occasionally are as much as 0.5 mm. in length, and rare fragments of brown hornblende. Green chlorite is abundant in patches, and locally there are narrow veins and other fillings of almost colourless serpentine.

(10) *Schists*

Small fragments of amphibole schists were noted freely at Harper's, and one large block (No. 14) about 7 in. across which shows small-scale folding well. The majority of the schists appear macroscopically to be identical and only a few, therefore, were sectioned. No. 14 has a number of leucocratic layers most of which are very thin (though one is ½ in. across), and other thin layers enriched in pearly thin-bladed crystals of actinolite with mean refractive index approximately 1.640, so that its content of FeO is about 8 per cent. The thin sections show that this rock has layers alternately enriched in actinolite or plagioclase (An_{35} to An_{40}), which latter is mainly in untwinned, considerably weathered grains averaging about 0.2 mm. in diameter (Fig. 9). There

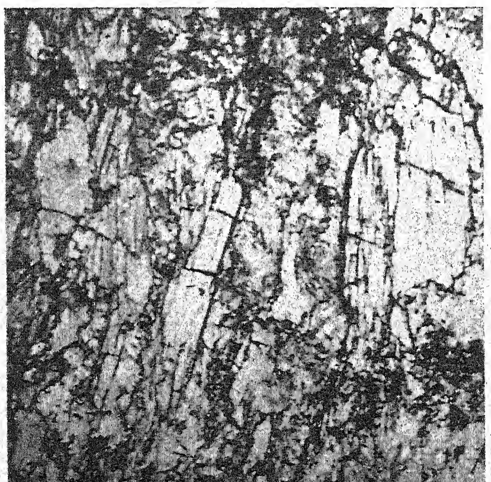


FIG. 9.—Amphibole schist (No. 14*b*) with its plagioclase severely speckled by weathering. (× 42).

are occasional large crystals of plagioclase 1mm. or more across which probably are residual from the original basic igneous rock now represented by this schist. Pale-green, almost colourless actinolite constitutes about 40 per cent. of the rock and is in sub-parallel blades which usually are under 0.5 mm. in length. There are rare grains of sphene and small prisms of zircon, while a little chlorite appears here and there.

In No. 28 the amphibole is in less amount than in the last rock and is grass-green in colour, while the feldspar (An_{30}) is in much coarser grains. In the thin section of No. 7, which otherwise is similar to that of No. 28, there is a large aggregate over 3 mm. across of crushed, almost colourless augite ; the same mineral also occurs in rare small strings of granules.

These schists are not the first that have been recorded from serpentinites of this northern region, for Turner and Bartrum (1929, p. 898) describe a diopside-plagioclase schist which was found as inclusions in serpentinite near Silverdale. There are schistose and gneissose diorites amongst the varied rocks of the so-called Albany conglomerates of Waitematan (mid-Tertiary) age of adjacent areas, but they result merely from cataclastic granulation ; the closest analogy to these schists in the serpentinites is in very varied schists, some of high grade, found as xenoliths in andesitic intrusions about one hundred miles farther north at Whangarei Heads (Bartrum, 1937). It is clear that the metamorphic basement that supplied these schists had very considerable extent. If it may be correlated, as appears reasonable, with the Otago metamorphic terrain, its age is approximately early Palaeozoic.

SOURCE OF INCLUSIONS IN THE SERPENTINITE AT HARPER'S

Many of the rocks that have been described in this paper are associated genetically with the serpentinites ; some, indeed, such as the troctolites, are constantly found as intrusions in these latter. Others, notably the schists, a granodiorite, diorites, and biotite-diorite porphyry, have no direct genetic connection with their host. The source of the schists has already been discussed ; that of the others is either in pre-existing igneous masses that have been involved in the thrusts and other orogenic movements that dismembered early large ultrabasic bodies and caused them to appear to-day as numerous, isolated, small lenses, or in conglomerates that contained suitable boulders. No conglomerates of constitution that could supply the inclusions in the serpentinite at Harper's and that antedate theorogeny have yet been found. On the other hand, diorites and granodiorite comparable with those found amongst these inclusions occur freely in the post-orogenic Albany conglomerates. The presumption is, therefore, that the batholiths which supplied the plutonic rocks to the Albany conglomerates were in existence prior to the orogeny that complexly disordered the Onerahi (late Cretaceous to mid-Eocene) sediments.

As suggested on an earlier page, the ultrabasic intrusions probably accompanied early phases of these earth movements.

ACKNOWLEDGMENTS

The writer is greatly indebted to Mr. J. Healy, of the New Zealand Geological Survey, for his kindness in taking him on several rounds of visits to many of the occurrences of serpentinites at a time when

transport was otherwise unobtainable, and to him and his colleague, Mr. C. A. Fleming, for valuable information. His thanks are also due to Dr. C. O. Hutton, of Otago University, who has generously given invaluable help by determining with the universal stage the optical properties of certain pyroxenes and by furnishing identifications of some of the minerals as well as references to literature.

REFERENCES

BARTRUM, J. A. (1924): The Geology of the Riverhead-Kaukapakapa District, Waitemata County, Auckland. *Trans. N.Z. Inst.*, *55*, 139-53.

——— (1944): Recent Petrographic Discoveries in the Silverdale-Wellsford Area, Auckland. *N.Z.J. Sci. and Tech.*, *26* (*Sec. B*), 28-35.

BENSON, W. N. (1926): Tectonic Conditions accompanying the Intrusion of Basic and Ultrabasic Rocks. *Mem. Nat. Acad. Sci.*, *19*, No. 1.

——— (1944): The Basic Igneous Rocks of Eastern Otago and their Tectonic Environment, Part 4. *Trans. Roy. Soc. N.Z.*, *74*, 71-123.

FERRAR, H. T. (1934): The Geology of the Dargaville-Rodney Subdivision. *N.Z. Geol. Surv. Bull. 34*.

FINLAYSON, A. M. (1909): The Nephrite and Magnesian Rocks of New Zealand. *Quart. J. Geol. Soc.*, *65*, 351-81.

FLETT, J. S. and HILL, J. B. (1912): The Geology of the Lizard and Meneage. *Mem. Geol. Surv. Eng. & Wales.* Explanation of Sheet 359.

HARKER, A. (1932): "Metamorphism." Methuen and Co., Ltd., London.

HESS, H. H. (1933): The Problem of Serpentinization and the Origin of certain Chrysotile Asbestos Talc and Soapstone Deposits. *Econ. Geol.*, *28*, 634-57.

HUTTON, C. O. (1936): Igneous Boulders from the Lake Wakatipu District. *Trans. Roy. Soc. N.Z.*, *66*, 27-34.

NEMOTO, T. (1938): A New Method for determining the Extinction Angle of Monoclinic Minerals, especially of Pyroxenes and Amphiboles, by means of Random Sections. *J. Fac. Sci. Hokkaido Univ.*, *Ser. 4*, *4*, 1-2, 107-12.

READ, H. H. (1931): The Geology of Central Sutherland. *Mem. Geol. Surv. Scotland.*

ROSENBUSCH, H. (1907): "Mikroscopische Physiographie der Massigen Gesteine."

TURNER, F. J. and BARTRUM, J. A. (1929): The Geology of the Takapuna-Silverdale District, Waitemata County, Auckland. *Trans. N.Z. Inst.*, *59*, 864-902.

NOTHOFAGUS POLLEN FROM THE CRETACEOUS COAL MEASURES AT KAITANGATA, OTAGO, NEW ZEALAND

By M. T. TE PUNGA, Victoria University College, Wellington

(*Received for publication, 26th June, 1947*)

Summary

Nothofagus pollen from the New Zealand Cretaceous at Kaitangata is described as a new species, *Nothofagus kaitangata*. The dominance of a six pore number shows closer affinity to living South American species than to present New Zealand species. This is apparently the first record of *Nothofagus* in beds known to be older than Tertiary in New Zealand.

INTRODUCTION

THE history of the *Fagaceae* in the Southern Hemisphere has long been an intriguing subject of botanical enquiry. At present the family is represented in New Zealand by a single genus, *Nothofagus*.

Living representatives of this genus, which is confined to the temperate portion of the Southern Hemisphere, are also found in Tasmania, Australia, and South America (Cheeseman, 1925).

Ettingshausen's determination of *Fagus*, which is essentially a Northern Hemisphere genus, in the Tertiary of New Zealand and Australia has been the focal point of considerable controversy. The reader is referred to Cranwell's important account of southern beech pollens for a summary statement of our present knowledge of the *Fagus* question (Cranwell, 1939). In this paper the author is mainly concerned with establishing the presence of *Nothofagus* in the New Zealand Cretaceous. It may be noted here, however, that careful study of the abundant and well-preserved pollens in New Zealand coals and lignites from Cretaceous to Quaternary age should provide solutions to many of the problems concerning the history of the *Fagaceae* in this country.

Nothofagus pollen has been recorded from the New Zealand Pliocene at Whangamarino and Kaikorai (Cranwell, 1939) and from the New Zealand Oligocene (?) at Ohai (Te Punga, 1945). Cranwell (1940) noted that *Nothofagus* pollen was present in coal samples from the Eocene of Westland.

AGE OF THE KAITANGATA COAL MEASURES

The sequence of beds in the Kaitangata district was found by Ongley (1939) to be as follows:—

	Age	
4. Wangaloa Series	Danian	Upper Cretaceous.
3. Brighton Series	Upper Senonian	
2. Taratu Series	Probably Lower Senonian or Turonian	
1. Kaitangata Series......	Probably Turonian	

"The Kaitangata Series is a set of thick beds of coarse conglomerate separated by thin, finer conglomerate and pebbly sandstone and contains the well-known coal-measures of Kaitangata . . . . . No fossils were found, so their age cannot be directly determined. They are, however, the first beds deposited after the Hokonui orogeny and so are later than Jurassic. They also underlie the Brighton fossiliferous bed and so cannot be later than Cretaceous. The Hokonui orogeny probably endured a considerable time and the interval between the Kaitangata and the Brighton was comparatively short, so that the Kaitangata beds are not much older than the Brighton ones and are probably Turonian."

PREPARATION OF MATERIAL

The coal examined was a roof-to-floor sample from Samson's Dip Section, Kaitangata (C.S. 273). This material was obtained through the courtesy of Mr. W. G. Hughson of the Coal Survey, Department of Scientific and Industrial Research. The pollen was separated from the coal matrix using the method outlined by Te Punga (1945), and after staining with basic fuchsin, twelve glycerine jelly mounts were prepared (slide nos. 273/1 to 273/12). The remainder of the pollen concentrate was stored for future reference in a solution of 10 per cent. glycerine to which a small crystal of phenol had been added.

DESCRIPTION OF THE *Nothofagus* POLLEN

All the grains have been considerably flattened by the pressure to which the coal seam has been subjected. The apparent shape and size is thus a distortion of the original form. However, if the material has been compressed vertically without horizontal distension (Walton, 1940, p. 8) the distortion in proximal, distal, or side views may not be very great. Nearly all the grains have been compressed with their equatorial planes parallel to the bedding planes so that only polar views are preserved. So far only one grain (poorly preserved) has been noted in which the equatorial plane was apparently perpendicular to the bedding plane, thus presenting an equatorial view. The description below is therefore based on polar views. All the grains so far observed have been ruptured along the furrows—apparently those not ruptured before entombment were ruptured by the later compression of the coal sediment.

Nothofagus kaitangata n.sp. (Fig. 1)

Grain rounded, but somewhat angular due to fissures produced by rupturing along the furrows. Equatorial diameter, as measured in polar view, ranging from 23-38 mu, the majority lying between 27 and 30 mu (average size of 50 grains, 28 mu).

The ruptured grains show clean, gaping fissures, averaging 3-5 mu in depth, arranged symmetrically around the equator, the distance between adjacent fissures being about 15 mu.

Pores 5 to 7 in number, the majority having 6. Two counts, each of 50 grains, gave the following results :—

Number of Pores	4	5	6	7	8
A. Slides 273/1-273/6	0	4%	84%	12%	0
B. Slides 273/7-273/12......	0	8%	80%	12%	0
Average	0	6%	82%	12%	0

Exine very thin, approximately 0.5 mu, evenly covered with tiny pointed papillae, each papilla being about 0.75 mu across the base and 0.75 mu in height. Distance between tips of adjacent papillae about 1 mu. Approximately 80-90 papillae per 100 sq. mu. (As measurement of the tiny papillae and their spacing is necessarily approximate only, the author suggests that for *Nothofagus* pollen quotation of the number of papillae per 100 sq. mu of exine would facilitate comparison of the concentration of the papillae in the various species).

Because of the manner of its preservation *Nothofagus kaitangata* presents only three characteristic features for comparison with other species—size, pore number, and ornamentation. Cranwell's brief description of *Nothofagus alessandrii* (Cranwell, 1939) stating that " the pollen is .026-.030 mm., thin walled, delicately flecked, and has 5 to 7, but usually 6 pores," could be applied in general to *Nothofagus kaitangata*. However, without more precise information on the thickness of the exine and the nature of the ornamentation the comparison cannot be carried further. Of the other species described by Cranwell

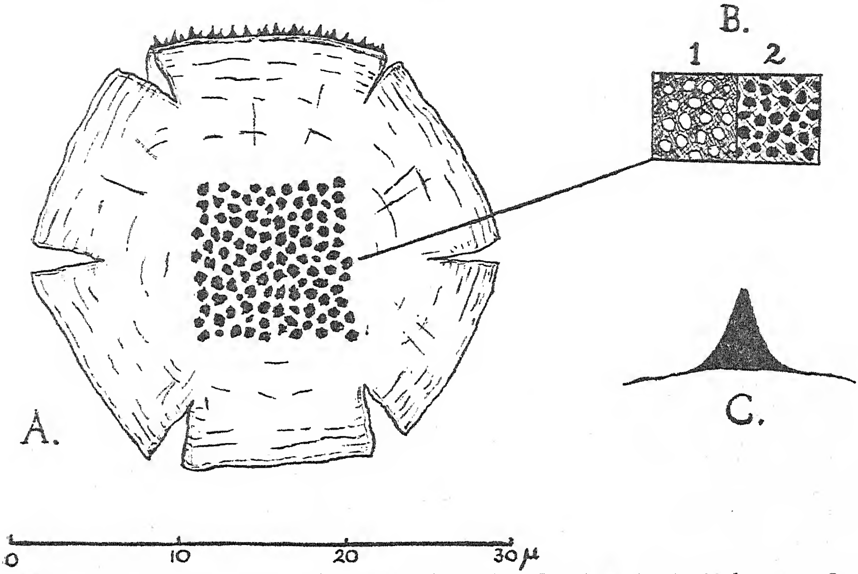


FIG. 1: A.—Polar view of ruptured grain showing typical shape and ornamentation.
B.—Ornamentation:
(1) In surface view at high adjustment.
(2) In surface view at low adjustment.
C.—A single papilla showing shape in lateral view (not to scale).

(1939), only *Nothofagus pumilio* has a dominant six pore number, but unlike *Nothofagus kaitangata* the exine is "almost, if not wholly, smooth."

Cranwell (1939) noted that the pores of the living South American species were fewer in number than in the New Zealand series, *Nothofagus truncata* with maxima on six and seven pores being the only New Zealand species which approached the low numbers of the South American group. *Nothofagus kaitangata*, with its dominant six pore number, thus shows a closer affinity to the present South American species than to any living New Zealand species.

ACKNOWLEDGMENT

The author extends his thanks to Dr. I. V. Newman, for his courtesy in providing microscope facilities, without which this investigation could not have been carried out.

REFERENCES

CHEESEMAN, T. F. (1925): "Manual of the New Zealand Flora." Second Edition, Wellington.

CRANWELL L. M. (1939): Southern-Beech Pollens. *Rec. Auck. Inst. and Mus.*, *2*, 175-96.

——— (1940): Pollen Grains of the New Zealand Conifers. *N.Z.J. Sci. and Tech.*, *22*, 1B-17B.

ONGLEY, M. (1939): The Geology of the Kaitangata-Green Island Subdivision. *N.Z. Geol. Surv. Bull. 38.*

TE PUNGA, M. T. (1945): "A New Zealand Coal Study." Jacob Joseph Scholarship Thesis, Victoria College Library.

WALTON, J. (1940): "An Introduction to the Study of Fossil Plants." Adam and Charles Black, London.

THE WANGANUI-WANGAEHU IRONSANDS

By J. FINCH, N.Z. Geological Survey, Department of Scientific and Industrial Research

(*Received for publication, 20th March, 1947*)

Summary

An examination of the coastal dune sands between Wanganui and Wangaehu Rivers indicated they are very low in iron-ore content. A detailed mineralogical analysis showed the greater part of these sands is derived from Tertiary sediments and volcanic rocks in the upper reaches of the Wanganui River.

INTRODUCTION

WITHIN recent years intensive efforts have been made in this country to utilize the titaniferous ironsands in an iron and steel industry, and it was believed that the valuable metal vanadium could become an important by-product. Although the areas so far investigated have shown a reasonable concentration of iron-ore, there are, nevertheless, as shown by Wylie (1937), Hutton (1940, 1945), and Munro and Beavis (1945), certain mineralogical and metallurgical aspects that complicate the project economically. In the light of this previous work the author has investigated the possibilities of turning to use the iron-bearing sands occurring between Wanganui and Wangaehu Rivers, for it has been suggested that these sands might be of considerable value should an iron industry become established.

PREVIOUS WORK

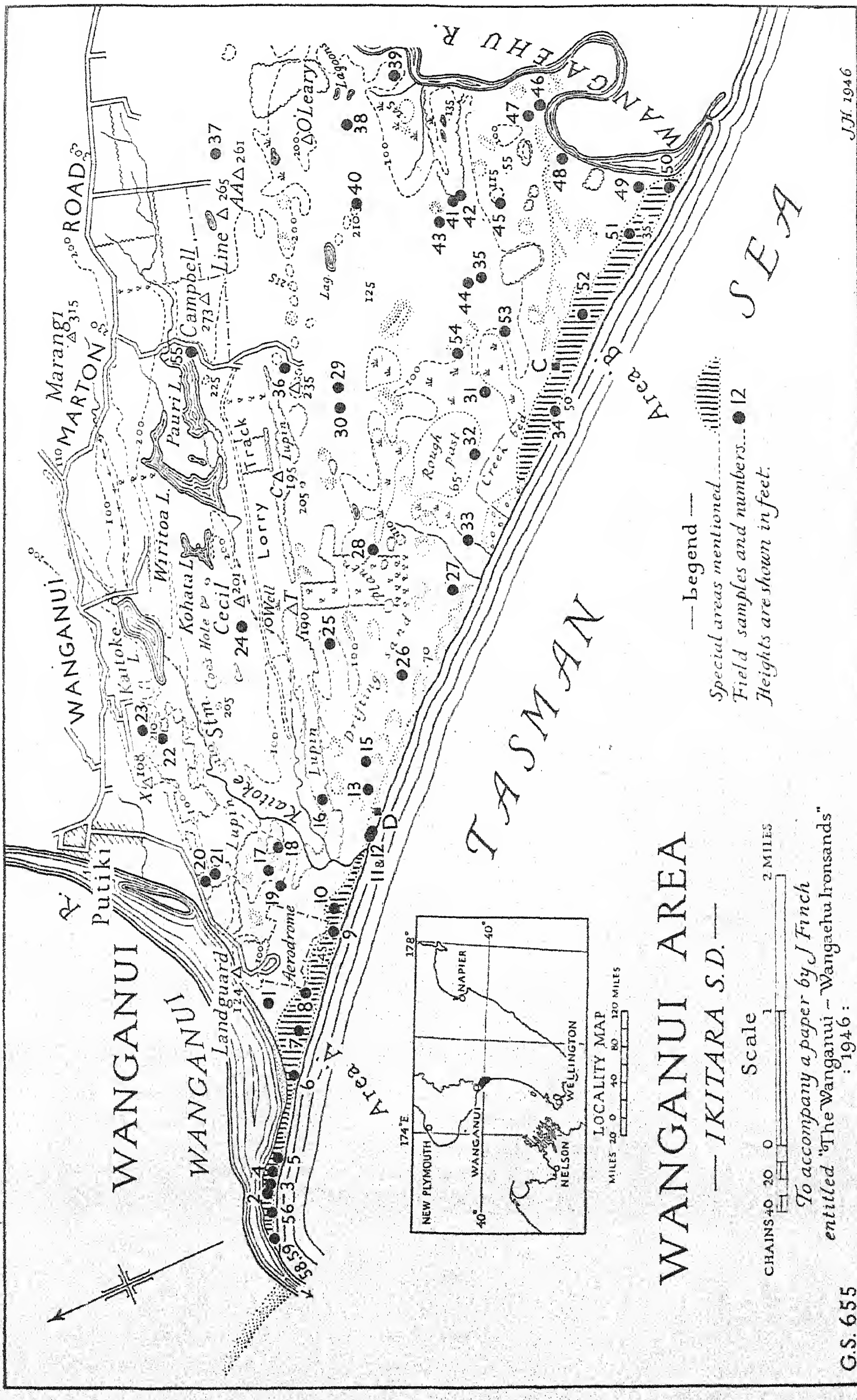
As far as the author is aware, nothing has been published dealing with the economic or mineralogical aspects of the ironsands now under consideration. It should be noted, however, that Park (1887) described them as blown sands of volcanic and sedimentary origin, and Cockayne (1911) discussed them very briefly during the course of an ecological study of dune sands in New Zealand. Neither of these writers considered the iron-ore present in them as worthy of mention.

AREA INVESTIGATED

The present author made a preliminary inspection of the whole coastal strip lying between the Wanganui and Wangaehu Rivers, bounded on the north-east by the main Wanganui–Marton Road; this area covers about 15,000 acres. A considerable portion of the area nearest the main road, was found to be completely devoid of any sand, and therefore was not considered any further.

GENERAL TOPOGRAPHY AND DISTRIBUTION OF SAND

Immediately south of Wanganui River, in the Landguard Bluff - Putiki Cliff vicinity, the ironsands are observed to be resting on Pliocene and Pleistocene (?) bedded sandstones, grits, clays, and conglomerates. From this locality the land-level drops sharply in the direction of the coast, but more gently towards Kaitoke Stream. The coastal strip from Wanganui River to Kaitoke Stream and extending inland for distances ranging from 3–20 chains is composed entirely of very recent loose sands with no indication anywhere of underlying formations. (This is area (A) in Fig. 1). A higher sand-covered belt that is initiate



WANGANUI AREA
— IKITARA S.D. —
Scale
CHAINS 40 20 0 1 2 MILES
To accompany a paper by J Finch
entitled "The Wanganui – Wangaehu Ironsands"
: 1946 :
— Legend —
Special areas mentioned
Field samples and numbers ● 12
Heights are shown in feet.
TASMAN
SEA
WANGANUI
WANGANUI
WANGAEHU R.
Putiki
Landguard
Aerodrome
Kaitoke L.
Wiritoa L.
Kohata L.
Pauri L.
Cecil Stn
Cons Hole
Well
Lorry Track
Lupin
Drifting
Rough Past
Creek Bed
Campbell Line
O'Leary
Lagoon
Marangi
MARTON ROAD
Area
Area
LOCALITY MAP
MILES 20 0 40 80 120 MILES
NEW PLYMOUTH
WANGANUI
NAPIER
WELLINGTON
NELSON
174°E
178°
40°
G.S. 655
J.H. 1946

FIG. 1

at Landguard Bluff continues intermittently, roughly south-east, as far as Wangaehu River. The northern limit of part of these sands is marked by a number of small lakes situated along a line oriented approximately north-west between the two main rivers. Inland from this chain of lakes the country is devoid of dunes or recent sands. From this line the land-levels drop towards the beach with an irregular gradient, this uneven surface consisting of loose shifting sands in some areas, fixed dunes in others, clay and cemented horizontal sand formations of varying types, and also swamps. The area drained by Kaitoke Stream extends well inland towards Kaitoke Lake and is relatively flat country covered in some places with older sands of unknown depth, but generally consists of good grazing land. Between the Kaitoke Stream and the mouth of Wangaehu River most of the coast-line is raised a few feet above the present beach-level. The greater proportion of the coastal area south-west of the creek is covered with a variety of sands, but, nevertheless, there are to be found isolated patches where the sand has been entirely removed by wind, or, alternatively, on which sands have never been deposited; evidence of the latter possibility is to be seen in the presence of "mesa" like formations, (Fig. 2) up to 200 yards long, occurring at various localities over the more seaward and eastern limits of the area under discussion. These prominences, composed of claystones, grits, and conglomerates, are older than, and appear to lie conformably on, the land surface on which the shifting sands are now resting, and they are high enough above the surrounding sands to be completely devoid of them.

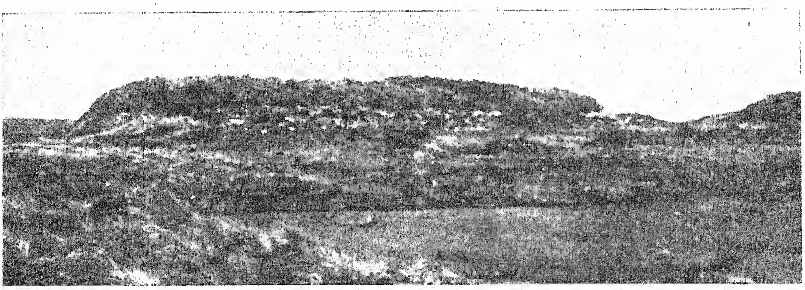


FIG. 2.—A coastal view showing a typical "mesa" like formation approximately 200 yards long covered with scrub. An extensive area of lag-gravel occupies the lower right foreground. In the middle foreground irregular dunes separated by smaller lag-gravel flats are visible.

Referring again to clay and cemented formations of various types, we must remember that these are not necessarily associated with the "mesa" like formations and that they are irregularly distributed over most of the waste area concerned in this investigation. They may best be described as usually low-lying patches, devoid of sand, and consisting of clay-pan or hard-pan with underlying loose sand or clay; also, some previously sand-covered horizontal clay and grit formations have been exposed at irregular intervals through the action of flood-water and wind.

Several small creeks drain very localized areas and some of the swamps, but do not appear to be flowing continuously, and cannot, therefore, be regarded as important topographic features. Kaitoke Stream and two small creeks make up the surface drainage system of the major portion of the area under consideration.

The sand-dunes are very irregular, and hence complicate still further problems concerning the commercial utilization of the ironsand. As previously mentioned, 15,000 acres of country have been examined, and for the purposes of this discussion may be sub-divided as follows :—

(1) 7,000 acres of old permanently fixed sand-dunes in addition to valuable grazing lands devoid of any sand.

(2) 8,000 acres of sand-dune areas and other waste lands that might possibly be considered from the commercial point of view. Within the latter area, however, there are about 3,800 acres of swampy areas, clay and iron-pan formations, and other areas free of sand. In addition, irregularly distributed patches of scanty vegetation, although occurring on the sandy areas, are useful for grazing.

Therefore it is clear that considerably less than 4,200 acres of suitable land are available as a source of ironsand, and it is of the greatest importance to remember that this does not occur as one block ; it is distributed irregularly over the whole 8,000 acres.

While it is usual for the swampy areas to be situated within or adjacent to extensive dune areas, the depth of sand within these swamps is very uncertain. It is the writer's opinion that this may not exceed 1 ft., for undoubtedly some of the more northerly swamps appear to have no sand in them. At one locality (marked " C " on the map), a few chains from the beach, running water seeps from the nearby sandy swamp area and it appears to originate from the upper surface of a hard clay-pan, 4-5 ft. below ground-level. This suggests that the possible depth of sand in this particular swamp is about 2-3 ft. A further indication of the depth of sand on the coast is obtained at point " D " (see Fig. 1) where an outcrop of green mudstone is found ; this appears to be horizontal and there is nothing to suggest that it does not lie under the beach sand and possibly extend inland, in which case the depth of sand would be limited considerably.

In summing up, therefore, it may be said that reasonably exploitable ironsands cover no more than half of 8,000 acres, and these sands are grouped as follows :—

(1) Clean shifting sands ranging from 1–40 ft. deep and grouped into a few areas :

(2) Dunes temporarily and loosely held by lupins, pingao, and marram grass; the depth is very irregular, and a wide variety of dune forms* occur (Figs. 3 & 4). Although some of these have a haphazard distribution, there are, nevertheless, two well defined unbroken areas containing this type of dune. The first of these dune systems occupies that portion marked Area (A) in Fig 1, and described earlier in this paper ; the second system of dunes makes up the coastal strip about 20 chains wide, and extends from Wangaehu River mouth north-west along the coast for two miles (see Fig. 1, Area (B) :

(3) Extensive areas of flat, low-lying sand partly under shallow water and partly covered by light and heavy vegetation. For want of further information the average depth of sand in these areas has been assessed at 2 ft. :

(4) Distinct from the sands considered under (3) there are afforested areas which would require special consideration if any attempt were made to recover sand from them.

*Many of those described by Cockayne in Parliamentary Papers C-13 can be observed in the Wanganui-Wangaehu sand-dunes.

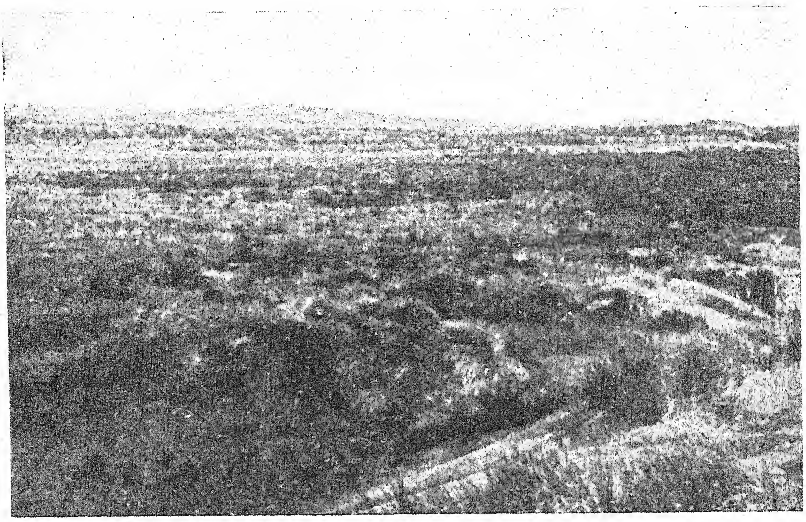


FIG. 3.—A view looking south towards the coast, showing a typical swamp flat bounded by sand-dunes.

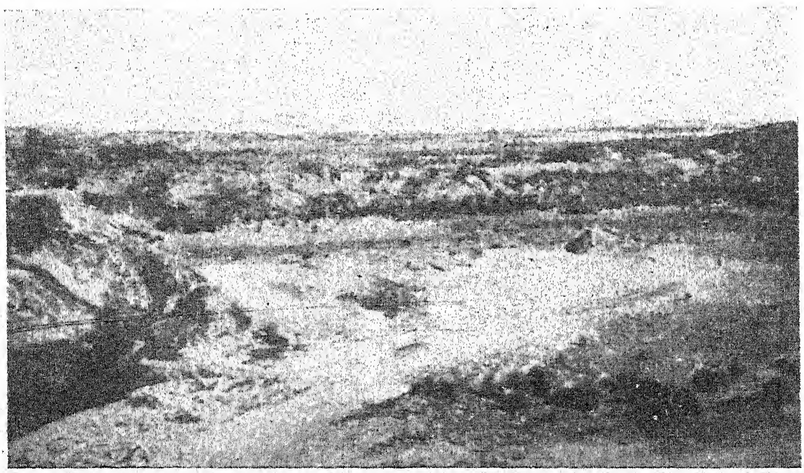


FIG. 4.—A view looking seawards, illustrating the irregular distribution of sand-dunes in semi-swamp areas.

QUANTITY OF IRONSAND

The figure of 16 cubic feet per ton was used to calculate the weight of ironsands considered, and the following figures have been obtained :

	Tons
Shifting dunes, afforested areas, and isolated patches of loosely held sand	53,300,000
Large stretches of lightly held dunes (Areas (A) and (B)	12,000,000
Flat, low-lying sands	4,300,000
Total quantity	69,600,000

BEACH CONCENTRATES

In addition to the dune-sands described above, beach concentrations of ironsands occur. They commence at the mouth of the Wanganui River and extend south-east three and a half miles along the beach. The black sand here was found invariably buried below a veneer of much lighter coloured sand. In view of the highly variable thickness of the overlying sand and the irregular volume of the ironsand and its erratic concentration, an estimation of the quantity of iron-ore can be only very tentative. At the mouth of Kaitoke Stream the concentration of ironsand reaches a maximum, and the volume of sand is therefore of some importance. The very high concentration of this particular ironsand is, however, extremely local, and its mineralogical assemblage is unique for this area. The total weight of these beach concentrates has been estimated by the author at 13,000 tons, but owing to the action of sea and wind, this quantity will vary considerably from time to time.

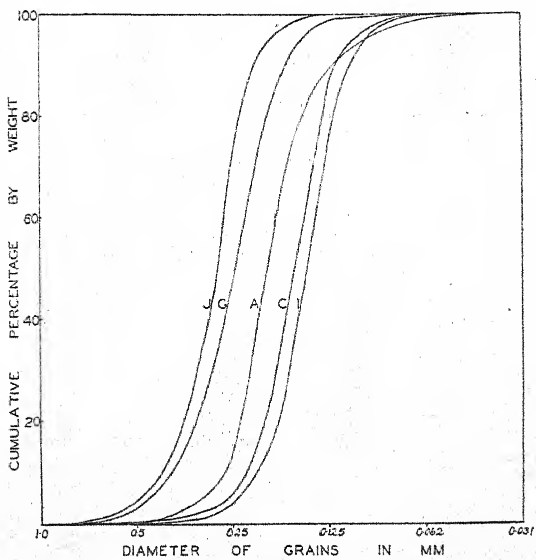


FIG. 5

GRADING ANALYSES

Eleven samples of representative sands were graded by using U.S. Standard Sieves. The results of some of these grading analyses are shown as summation curves in Fig. 5, and all of them are represented by the histograms (Fig. 6). It has been found that although the beach deposits from Kaitoke Creek (I) and near Wanganui River mouth (J) are better graded than an average dune-sand,—*e.g.*, (G)—the distinction is not as marked as that described by Carroll (1939) and verified by Hutton's work on other New Zealand beach ironsands. The dune samples A, B, and C, showing a relatively good grading, all come from near the mouth of Wanganui River, where the greater portion of the dunes is made up of well bedded sands. In this connection Bagnold (1941) points out that such thin-bedded sands may very well be wind-blown, and these structures are typical of some aeolian deposits

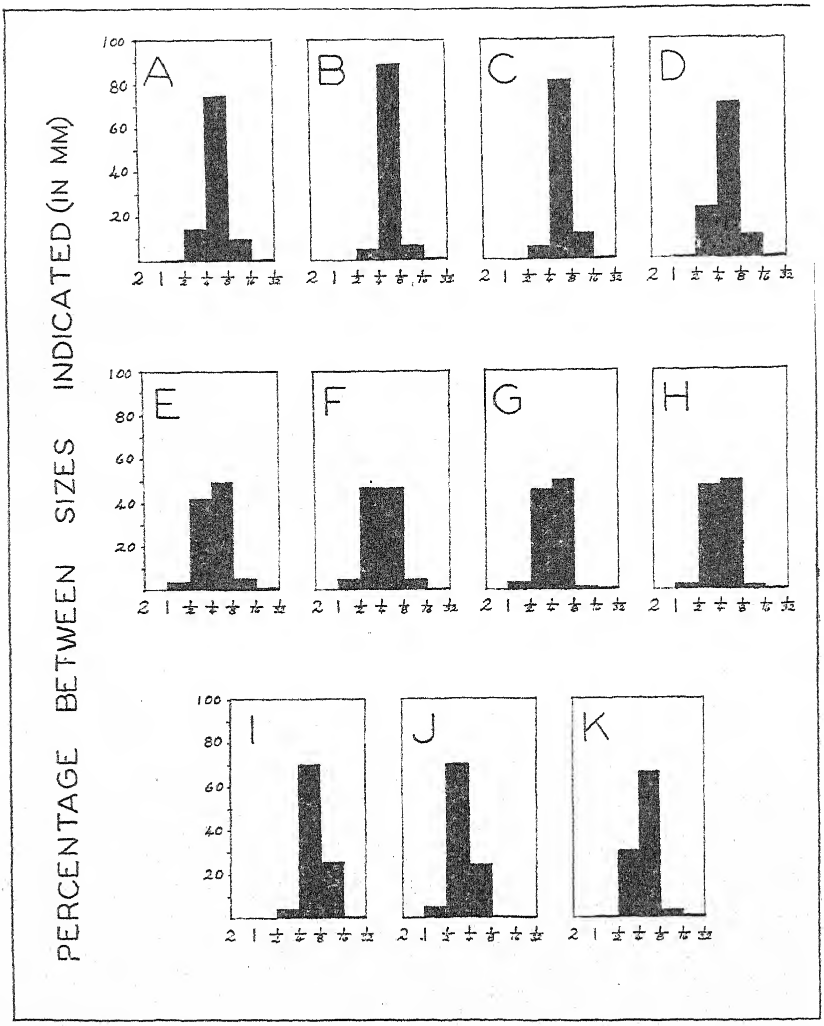


FIG. 6.—Histograms showing the mechanical analyses of representative Wanganui-Wangaehu ironsands.

A = P 10694 (2)	F = P 10699 (34)	
B = P 10695 (3)	G = P 10700 (36)	
C = P 10696 (4)	H = P 10701 (43)	(Figures in brackets are
D = P 10698 (15)	I = P 10697 (12)	field sample numbers).
E = P 10693 (1)	J = P 10703 (59)	
	K = P 10702 (50)	

described by Grabau ("Principal of Stratigraphy," p. 704). Still, the evidence of the grading analyses suggests that the dunes are merely remnants of recent water-laid deposits. Further, it should be noted that although the graphs (Fig. 5) for I and J are identical in shape, there is a marked difference in the median diameter. Both these deposits contain a high percentage of iron-ore, but, since the former sand has had its iron grains considerably abraded by movement along the coast, the average grain-size of this size is less than that of J. Of the eleven samples graded, by far the greatest percentage of grains

was retained on two sieves—viz., those with mesh diameters of 0.25mm. and 0.125 mm. respectively. This is clearly shown in the histograms (Fig. 6). In the case of I, however, the average grain-size is distinctly smaller than that of the other samples owing to the high percentage of iron-ore, a mineral that is normally concentrated in finer screenings. This fact also contributes to the increase in the median diameter from sample I to sample J. An electromagnetic separation was made of 57 sand specimens and the results shown in Table I, where the samples have been grouped according to their magnetic content.

ELECTROMAGNETIC SEPARATIONS

TABLE I.

Percentage Magnetic Fraction (By weight)	Number of Samples	
< 4	7	
4–6	5	
6–9	17	
9–12	14	
12–16	10	
16–20	2	
> 20	2	(both are beach concentrates)

The average of fifty-five samples (excluding the two samples of beach concentrates) is 8.88 per cent.

The individual percentages of these samples which have been graded and examined microscopically are shown in Table II.

TABLE II.

Sample No.	Percentage Magnetic Fraction (By weight)
P 10693	17.46
P 10694	12.60
P 10695	8.07
P 10696	7.90
P 10697	78.70
P 10698	15.14
P 10699	8.03
P 10700	3.68
P 10701	9.23
P 10702	3.73
P 10703	21.57

It will be noted that the figures in Table II are far greater than should be obtained by calculating the percentage of iron-ore from each of the corresponding histograms of Figs. 6 and 7. While this fact is partly explained by the greater specific gravity of iron-ore relative to that of the other sand constituents, the anomaly is chiefly the result of contamination, which is due entirely to magnetic iron-ore inclusions in other mineral grains, chiefly hypersthene and augite ; this reason for contamination has also been shown by Hutton.* Grain-counts of the eleven magnetic fractions have been made to illustrate the high percentage of contaminating grains, and the results are shown in Table III.

**Op. cit.*

TABLE III.

Dune Samples		Beach Samples	
Sample No.	Iron-ore Grains in Magnetic Fraction (Per Cent.)	Sample No.	Iron-ore Grains in Magnetic Fraction (Per Cent.)
P 10693	79	P 10697	91
P 10694	79	P 10703	86
P 10695	59		
P 10696	78		
P 10698	79		
P 10699	68		
P 10700	23		
P 10701	37		
P 10702	46		
Average	61		

NOTE.—Over six hundred grains were counted in each of these eleven magnetic fractions, giving an accuracy of at least 98 per cent.

These figures are for a grain count only and would therefore be still lower on a volume basis, since, as shown in Fig. 4, the iron-ore grains are considerably smaller than the majority of other grains.

In conclusion, it is safe to assume that, on an average, the magnetic fraction of all the dune-sands would certainly not contain more than 60 per cent. of iron-ore. The beach samples have not been included in this estimate as the amount of sand involved is of such minor importance, and their study serves only to indicate the high degree of concentration that may occur in water deposits.

Using the above figure of 60 per cent., we obtain the figure of 5.3 per cent., representing the maximum of truly magnetic material in the ironsands of the Wanganui-Wangaehu area. Finally, it must be remembered that this final figure arrived at for the magnetic content does not represent the amount of pure iron-ore; Wylie,* Hutton,* and Munro* have shown that impurities may be fairly considerable in such iron-ore.

ECONOMIC CONSIDERATIONS

Some additional economic aspects of the utilization of the Wanganui iron-ores are briefly summarized below :—

(1) The very low iron-ore content of most of the sand :

(2) As distinct from other Taranaki ironsands—*e.g.*, Patea and Fitzroy—those lying between Wanganui and Wangaehu Rivers are very widely distributed with intervening areas barren of workable iron-sands. This makes the transport costs a special consideration.

(3) In the event of dry magnetic separation methods being used in the field, drying costs would be considerable.

(4) If the latest wet magnetic separation method were used, a fixed plant would probably be required owing to the large flow of water necessary.

(5) Special consideration would need to be given to the question of the utilization of afforested and stock-grazing lands which occupy a considerable area.

**Op Cit.*

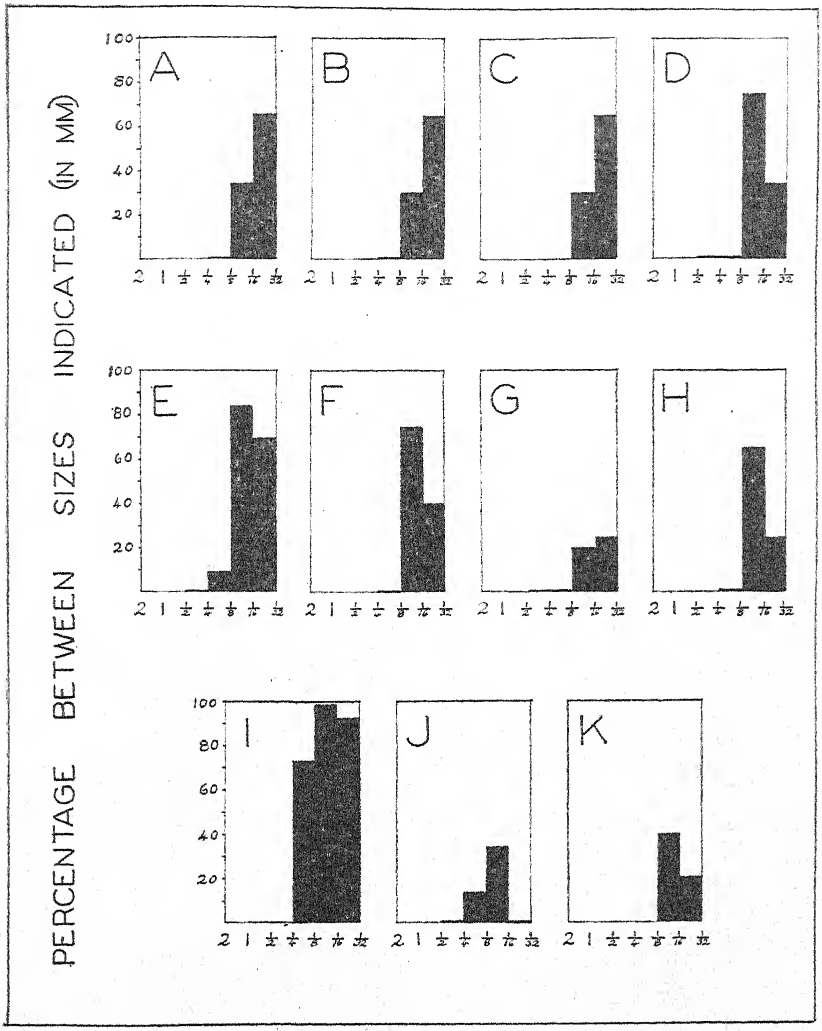


FIG. 7.—Histograms illustrating the approximate percentage of iron-ore grains in each of the fractions represented in Fig. 6.

MINERALOGY

The most important constituents in the mineral assemblage of the sands are augite, hypersthene, feldspar, hornblende, quartz, and iron-ore; however, it should be noted that, although ilmenite is generally absent, in one sample up to 1–2 per cent. of it has been noted. The mineral assemblage is similar to that in the Patea ironsands as samples contain iron-ore, plagioclase, quartz, pyroxenes, and amphiboles as major constituents, and zircon and garnet as minor constituents. The minerals present are slightly more varied than those at Patea, and, although apatite has been generally recorded in the latter sands, it was recognized in only one of the heavy mineral separations made from the Wanganui-Wangaehu ironsands. Again, olivine, not recorded as occurring at Patea, is present as a minor constituent in most of the samples now under consideration. Compared with those of Fitzroy,

the minor constituents of the Wanganui-Wangaehu ironsands have a slightly more varied mineral assemblage; actinolite, collophanite, pyrite, and aragonite, recovered in the former, are all absent from the latter, although shell fragments of an undetermined species are present.

Magnetite

On account of quantitative chemical tests for titanium and also its strongly magnetic properties, the bulk of the iron-ore has been assumed by the author to be titanomagnetite similar to that occurring at Patea and Fitzroy. Magnetic separations with a weak magnet showed that non-magnetic iron-ore constitutes a fraction of 1 per cent. of the total sand, so that titanomagnetite is the dominant iron-ore mineral. Inspection of a crushed sample of the non-magnetic iron-ore fraction showed the presence of haematite and rare chromite. This haematite almost certainly corresponds to the titanohaematite* from the Fitzroy ironsands, but verification of this was not possible owing to the difficulties involved in separation.

Chromite

Chromite is very rare, and it is recognized mainly in the finely ground non-magnetic iron-ore; occasionally small fragments were noted in the —230 screenings of some samples.

Ilmenite

Ilmenite is found in appreciable quantities in P 10697, but is not recognized elsewhere. The grains appeared to be almost identical with those of titanomagnetite where viewed in oblique illumination. The approximate quantity of ilmenite present was assessed from the following facts :—

(*a*) The non-magnetic fraction was 21 per cent. of the total sample by weight :

(*b*) A grain count of this non-magnetic fraction showed that only 20 per cent. of its grains were iron-ore :

(*c*) The iron-ore grains in this non-magnetic fraction are considerably smaller, but have a greater specific gravity than their associated ferromagnesian minerals :

(*d*) Chemical tests showed the amounts of titanium in the non-magnetic fraction to be high.

Thus the author has estimated that the ilmenite makes up 1–2 per cent. of the sample and that probably a very small fraction of titanohaematite is present in the non-magnetic iron ore.

Olivine

Olivine grains nearly all rounded to the extent of being almost spherical irrespective of size, occur in all fractions from —35 +60 mesh down to the finest fraction —230 mesh ; none were found showing any crystal outline. They are all colourless, many have a rough pitted surface, and they are usually free of inclusions ; the inclusions which do occur are small, scattered, and black. Only one grain displayed any cleavage. Two olivine crystals gave almost uniaxial figures, and the determination of γ for a few crystals ranged about 1.710 ; this suggests the olivines are rich in MgO. Of the fraction —36 +60 in one sample the olivine grains make up about 1 per cent.

*Described by Hutton.

Augite

Augite is by far the most abundant mineral in the ironsands, both dune and beach, and in the coarse fractions of some samples makes up to 75 per cent. of the grains. Usually the grains are well rounded, but in most fractions of all the samples the prismatic outline is shown in many grains. There are also fragments of larger crystals. All are coloured light-green, and faint pleocroism shows in some. Iron-ore inclusions are common in all except the finest of augite grains, and those grains contained in the magnetic fraction show either a few or a large number of small inclusions of iron-ore.

Hypersthene

This is a fairly abundant ferramognesian constituent in the ironsands of the dunes and beach and, in some coarse screenings of the sands, comprises from 15–20 per cent. of the grains, and, together with augite, in one sample comprised from 90–95 per cent. of the coarser fractions. While hypersthenes completely free of inclusions are frequent, iron-ore inclusions are common in all grain sizes and are just as important as in augite in causing the hypersthene grains to be taken up in the magnetic fractions. The prismatic outline is commonly well developed, with the crystal faces sharply defined ; in many hypersthenes the degree of rounding in all fractions is not as great as in the augite of corresponding grain size. Some hypersthenes have a black-speckled appearance due to an abundance of very small scattered iron-ore inclusions. The range in composition of the hypersthene is indicated by the refractive indices* determined on six grains as follows :

γ	α
1.717	1.701
1.702	1.689
1.702	1.689
1.697	1.686
1.718	1.702
1.701	1.689

*All values subject to error of $\pm$ .001.

Composites

The presence of fragments of glassy material or composite grains is very characteristic in the coarser fractions. Classed as composites are many grains made up of two or three small fragments of different minerals combined as one grain. There are iron-ore grains with traces of other minerals attached to their surface ; the grains, for purposes of grain counting, are classed as iron-ore and not as composites.

Plagioclase

The composition of the plagioclases showed a wide range from albite to fairly basic types, but it was difficult to decide whether they were derived from larger-zoned crystals or were fragments of crystals uniform in composition. Zoning is very pronounced in many of the plagioclase crystals retained on the 60 and 120 mesh sieves. Occasionally simple, but usually multiple, twinning of feldspars was observed in most samples, but such twinned crystals are not common, and, typically, the grains of all sizes range from an angular to a rather rounded shape.

Orthoclase

Very rare grains of orthoclase were observed in some of the samples, and two grains of microcline were found in one sample. All these grains were in the coarser grades and were angular.

Amphiboles

Blue-green, red-brown, and green-brown amphiboles are present in the sands examined. The green-brown variety which is by far the most abundant, occurs commonly as elongated grains with partly rounded ends, but sometimes contains iron-ore inclusions. It is abundant in all the samples examined, and common to all fractions of each sample. The red-brown hornblende is oxyhornblende similar to that described in the Fitzroy ironsand. It is common to all the samples examined, is found in both the coarse and fine fractions, and, in contrast with the two other varieties of amphiboles, is very much rounded. Refractive indices determined for two grains of oxyhornblende are as follows :—

$\alpha = 1.682$	$\alpha = 1.683$
$\beta = 1.712$	$\beta = 1.716$
$\gamma = 1.747$	$\gamma = 1.752$

The blue-green hornblende occurs only as a very minor constituent and was not found in all the samples examined. It is confined to the —120 mesh and smaller fractions and is usually in elongated crystals with well-rounded ends. The properties observed for one blue-green hornblende grain are as follows :—

γ = 1.674
$Z \wedge c$ = 14°
X = yellow
Y = bluish-green
Z = greenish-blue
$X < Y < Z$

In P 10703 one grain was found showing prismatic outline, a surrounding iron-ore cluster, and pleochroism suggesting kearsutite.

Clinozoisite

As a very rare constituent, this mineral was recognized in three samples only, where it occurred as anhedra and subhedra in the —120 +230 and —230 fractions.

Glauconite

Glauconite is exceptionally rare and occurs as rounded grains with aggregate appearance. It was observed in both the —120 +230 and —230 fractions.

Glass

In the finer fractions glass fragments were commonly observed as irregular brown grains. Others, either colourless or faintly coloured, showed a fibrous structure, although this was rare. Colourless non-fibrous glass was also observed.

Quartz

Quartz usually occurs in all gradings, but is absent from the finest grades in those samples high in iron-ore. Most grains are angular with a slight tendency to be rounded ; only a few are sharply angular.

Zircon

Zircon is a minor constituent, common to the dune and beach samples. Some grains are well rounded, but the majority are euhedral to subhedral, and a few contain small inclusions. The zircons are confined to the two finest grades, and within the —230 grading where they seem more common, their range in size is considerable.

Garnet

In contrast with zircons, the garnets have a great range in size, although the majority occur in the two finest grades. A few occur as chips with conchoidal fracture, most are subhedral to well rounded, and rare ones are sharply euhedral. They are mostly colourless, although some are pink, some brownish-pink, and rare ones pale purple. In many samples the garnets were relatively abundant in the fraction —120 +230—*e.g.*, in P 10697 this fraction consists of 99 per cent. iron-ore, the other 1 per cent. being very high in garnets and pyroxenes, while in P 10696, garnets, together with zircons, make up 2–3 per cent. of this fraction. The refractive index of a colourless garnet was 1.797 ± .002, and no manganese reaction was obtained from a chemical test; this indicates that the colourless garnets are of the almandite-pyrope series. The garnets are much more abundant than zircons in the fraction —120 +230.

Biotite

Two flakes of biotite, each about 0.5 mm. in diameter, were found in one sample, and a few minute fragments were recognized in the first fraction of this and one other sample. The refractive index for one of the larger flakes was determined as $\beta = 1.636$.

Muscovite

A few large cleavage laminae of muscovite were retained in the 18-mesh screen in one sample, and one or two much smaller flakes were found in another sample.

Sphene

Sphene is a rare constituent, although it occurs more often than the micas, apatite, and tourmaline. In the two finest fractions of a dune sample, P 10694, and in the —230 fraction of P 10697, a few rounded and sub-rounded grains are present.

Apatite

Several apatite grains were found, mostly in the —230 mesh fraction in P 10703, but were not recognized in any other samples. It occurred as fragments of larger crystals and as circular crystals. Rare apatite occurred in the —120 +230 fraction of the same sample.

Tourmaline

This mineral was found in only one sample—*viz.*, P. 10703, which contained two crystals in the finest fraction. These tourmalines were slightly broken at the ends and were pale blue.

Epidote

Epidote occurs in most samples, but always as a rare constituent. In one grain count only were epidotes as plentiful as olivine grains. They are subhedral and euhedral, while many have the characteristic aggregate appearance. Inclusions were not observed. Although the epidotes are colourless or only very faintly coloured, the considerable range in birefringance indicates a large range in composition from iron rich epidote to clinozoisitic epidote.

Non-magnetic Fractions

A grain count of the non-magnetic fractions was made, between five and seven hundred grains being counted in each preparation. The results are shown in Table IV. It should be noted that many of the rare constituents were observed only by inspection of the numerous preparations obtained during grading analyses.

TABLE IV.—MINERAL ASSEMBLAGE OF NON-MAGNETIC FRACTIONS

	P 10693	P 10694	P 10695	P 10696	P 10697	P 10698	P 10699	P 10700	P 10701	P 10702	P 10703
Augite	F	E	E	E	F	F	F	E	F	E	F
Hypersthene	C	B	B	B	C	C	C	C	C	B	D
Feldspar	B	E	E	E	A	D	C	E	C	E	C
Quartz	B	C	D	D	A	B	B	C	B	C	B
Composite	B	D	E	E	B	D	D	E	D	E	C
Hornblende (green-brown)	D	D	C	C	C	D	D	C	D	D	C
Hornblende (red-brown)	A	B	A	A	B	B	A	A	B	A	A
Garnet	B	A	A +	A	B	A	A	A	A	A	A +
Iron-ore*	B	B	A	A	B	A +	A +	A +	.	.	B
Zircon	.	A +	A +	A +	A +	A +	A +	A +	.	A +	A
Sphene	.	A +	A +	A +	.	.	.	.	.	.	.
Epidote	.	.	A +	.	A +	.	A	.	.	A +	A
Olivine	A	.	A	.	A	A	A	A	A	A	A
Hornblende (blue-green)	.	A +	A +	.	A +	A +	.	A +	.	.	A +
Carbonate (shell fr'ments)†	A +	A +	.	.	.	.	.	.	.	.	A +
Biotite	.	.	A +	.	.	.	.	.	.	.	.
Muscovite	.	.	A +	.	.	A +	.	.	.	.	.
Clinozoisite‡	.	.	.	.	A	.	A +	.	.	.	A
Tourmaline	.	.	.	.	.	.	.	.	.	.	A +
Apatite	.	.	.	.	.	.	.	.	.	.	A +
Glauconite	.	.	.	.	A +	.	.	.	.	.	A +

A+ = very rare. Many of these were seen only upon examination of the finer screenings.
A = $<$ 1 per cent.
B = 1 – 5 per cent.
C = 5 – 10 per cent.
D = 10 – 20 per cent.
E = 20 – 40 per cent.
F = $>$ 40 per cent.

*Includes ilmenite, chromite, and haematite (possibly).

†Although usually absent in medium and finer screenings, large shell fragments were present in many samples and were common in samples near the coast.

‡Includes clinozoisitic epidote.

ORIGIN

The occurrence between Wanganui and Wangaehu Rivers of titaniferous iron-ore similar to but in much lower concentrations than that at Fitzroy and Patea, and immediately north-west of Wanganui River mouth, makes it evident that at least part of these Wanganui-Wangaehu sands have drifted along the coast from the other areas. The high percentage of quartz, feldspar, and hypersthene, the occurrence of pumice south-east of Wanganui River, and the fact that the iron-ore percentage drops suddenly from the north to the south side of Wanganui River mouth all make it clear that the greater part of the sands has been brought down by the Wanganui River. The Lower Pleistocene rhyolite tuffs in the Aria Survey District and at the head of Ohura River in Tangitui district, together with the andesites of Ruapehu area, are all probably additional sources of iron-ore. That the Ruapehu

hypersthene andesites play an important part in contributing towards these sands is shown by the abundance of hypersthene present in them compared with its scarcity in sands west of Wanganui. The garnet, zircon, epidote, and other rarely occurring minerals may all have been derived from the Tertiary sediments as well as from the volcanic rocks in the upper reaches of the Wanganui River.

ACKNOWLEDGMENTS

I wish to express my thanks to Dr. C. O. Hutton for his guidance in the setting-out of this paper and assistance in identifying some of the minerals.

REFERENCES

BAGNOLD, R. A. (1941): "The Physics of Blown Sand and Desert Dunes."

COCKAYNE, L. (1909): "Report on the Sand Dunes of New Zealand." (Parliamentary papers C–13).

CARROLL, D. (1939): Movement of Sand by Wind. *Geol. Mag.*, *76*, 6–23.

GRABAU, A. W. (1913): "Principles of Stratigraphy," p. 704.

HUTTON, C. O. (1940): The Titaniferous Ironsand of Patea, with an Account of the Heavy Residues in the Underlying Sedimentary Series. *N.Z.J. Sci. and Tech. 21*, 190B–205B.

——— (1945): Vanadium in the Taranaki Titaniferous Iron-ores. *N.Z.J. Sci., and Tech.*, *27*, (*Sec. B*), 15–6.

——— (1945): The Ironsands of Fitzroy, New Plymouth. *N.Z.J. Sci. and Tech.*, *26* (*Sec. B*), 291–302.

MUNRO, A. D. and BEAVIS, G. (1945): The Constitution of Taranaki Ironsand. *N.Z.J. Sci. and Tech.*, *27* (*Sec. B*), 237–41.

PARK, J. (1887): On the Geology of the Western part of Wellington Province District, and Part of Taranaki, New Zealand. *N.Z. Geol. Surv. Rept.*, *18*, 24–73.

WYLIE, A. W. (1937): The Ironsands of New Zealand. *N.Z.J. Sci. & Tech.*, *19*, 227–44.

THE NEW ZEALAND

JOURNAL OF SCIENCE

AND

TECHNOLOGY

Editor: D. Cairns, M.Sc. (Assistant Editor: M. O'Connor, M.Sc.) Department of Scientific and Industrial Research, Wellington

VOL, 29. SEC. B | SEPTEMBER, 1947 | NUMBER 2

INVESTIGATION INTO THE VARIABLE SPEED SPINNING OF WOOL ON A RING SPINNING FRAME.

BY F. PUCH AND G. MCK. ALLCOCK, AUCKLAND INDUSTRIAL DEVELOPMENT LABORATORIES, DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

[*Received for publication, 26th January, 1947*]

FOREWORD

BY L.W. TATTERSFIELD, TATTERSFIELD LTD., AUCKLAND.

The necessity of employing unskilled adult labour in woollen mills has provided management with numerous problems, the most general of which can be summarized under the headings of "Costing" and "Maintenance of Quality Standards". In no department of the mill has the shortage of juvenile labour been more acutely felt than in the spinning room. The larger mills have organized classes where piecening and the principles of spinning are taught before new operatives are introduced to the mill. This has been found effective in reducing non-productive learning time, but the necessity of maintaining production under adverse labour conditions has provided the spur to investigations into machine efficiency generally, and in this respect it is thought that the following account of an investigation carried out by the Auckland Industrial Development Laboratories to determine the value of variable speed spinning on woollen ring frames will be of interest to those who contemplate the installation of woollen spinning frames; to those who are at present operating ring frames at constant speeds, and to those who are operating variable speed ring frames, but who, like the writer, have so far been unable to establish a formula for adjustment which will ensure good spinning over a wide range of counts.

The plant used for the investigation was a 200 spindle Gessner Patent ring frame, manufactured by Asa Lees of Oldham in 1932. As originally supplied, a 12 h.p. Squirrel Cage Metrovick motor was mounted above the headstock, and short centred V belt driven to a counter shaft directly above the main driving shaft. Variable speed was effected by means of a pair of cone pulleys, the belt striking gear being synchronised with the rise and fall of the ring plates. A small cam on the end of the ratchet shaft of the Scaife lifting motion held the striking gear out of action until the cop bottom had been formed. This set up was neat in appearance, but the excessive wear on the belt edges due to the strain of moving it backwards and forwards across the face of the cone pulleys with each cycle of the heart cam, made maintenance

a costly item. Belts supplied were of the endless leather laminated type, and difficult to fit, as the countershaft and end bearing had to be removed each time.

In 1935, upon the recommendation of the manufacturers, we installed a Siemens-Schuckert variable speed commutator motor with attached spinning regulator. This drive has proved most satisfactory. The operation of the spinning regulator will be described later, but it will suffice here to say that by means of a pair of cams, both the "basic" and the "cyclic" speed can be given a wide degree of variation. However, it must be borne in mind that if incorrectly set, the blessing of variable speed spinning becomes a menace, directly increasing yarn tensions where it is intended that relief should be given. The purpose of the investigation was to ascertain the correct setting of these cams, and to fix the most efficient base speed. The investigation has resulted in an over-all increase in production of at least 15 per cent., an improved yarn, less machine maintenance, and the satisfaction of knowing that we are getting the best out of our machines.

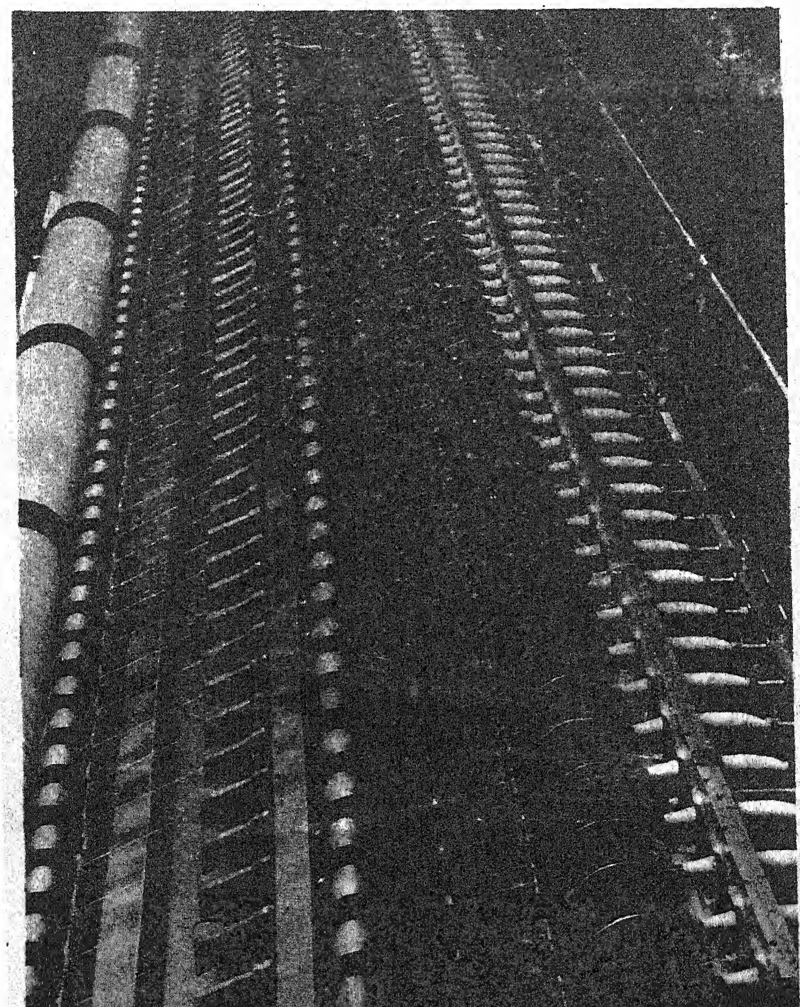


Fig. 1

Summary

The method of spinning wool fibres by the ring spinning system, and the basic causes of variation in spinning tension are briefly explained. Adjustments affecting the efficiency of operation of the machine are considered. An electronic spindle speed recorder which has been developed is described in some detail.

Recorder tracings and photographs taken at various stages of spinning enable tensions to be calculated from full scale "balloon" tracings.

The method is applied to a particular case, an ideal speed variation diagram is calculated and limitations in tuning the regulators to give this ideal diagram are discussed.

The method of calculation is simplified as far as possible; difficulties encountered and suggestions for facilitating future investigations are described.

INTRODUCTION

Although this report deals mainly with a particular case of wool spinning on a variable speed ring frame it is thought that the lack of information concerning tension-speed correlations warrants the inclusion of a simplified summary of the principles involved so that the desirability of having an accurately controlled variable speed drive can be more fully appreciated. The complexity of the forces encountered and the multiplicity of variable factors that affect yarn tension during spinning make it impossible at this stage to establish a simple formula for determining tensions. However, the method used in this investigation and the equipment developed are readily applicable to any particular case, and the experience gained will be invaluable in facilitating the execution of any future experiments.

For the benefit of users of similar frames mention is made of the adjustments and modifications found necessary to ensure consistent machine performance

Basic principles and desirability of variable speed drive

The path of the roving through the operating section of the machine is shown in Fig. 2.

The unspun roving is drawn from bobbins, passed through a drafting and false twisting system, and is delivered through the rollers A with the desired degree of fineness. A felt covered scavenger roller B serves, in the case of a breakage, to pick up and wind the roving, thereby preventing entanglement and breakage of adjacent rovings. Immediately upon emerging from the rollers A on its way to the guide eye C, the roving is twisted due to the rotation of the traveller D on the ring E, i.e. the actual spinning process takes place just below the rollers A. This twisting results in a considerable increase in strength and the finished yarn passes through the traveller and is wound uniformly on the bobbin F, mounted on the rapidly rotating spindle G. The traveller rotation is caused by the drag on the yarn passing to the bobbin, the traveller speed lagging behind the spindle speed to the extent that the yarn delivered from above is wound upon the bobbin.

The ring rail guides the yarn periodically up and down, the time of upward movement being long compared with the downward period so that the yarn comes to lie in conical layers separated by cross layers, thereby ensuring satisfactory unwinding for later processes. In addition to this periodic movement the ring rail is given a superimposed progressive lifting motion by means of a ratchet mechanism so that the winding action is slowly traversed from bottom to top of the bobbin.

The effect on tension of winding on different diameters will now be considered. Assuming that the traveller is rotating at constant speed, the centrifugal force and therefore the frictional resistance of the traveller remains constant. In Fig. 3, R is the traveller resistance and Pd and d represent the tensions in the thread between the traveller and the bobbin when winding on the large

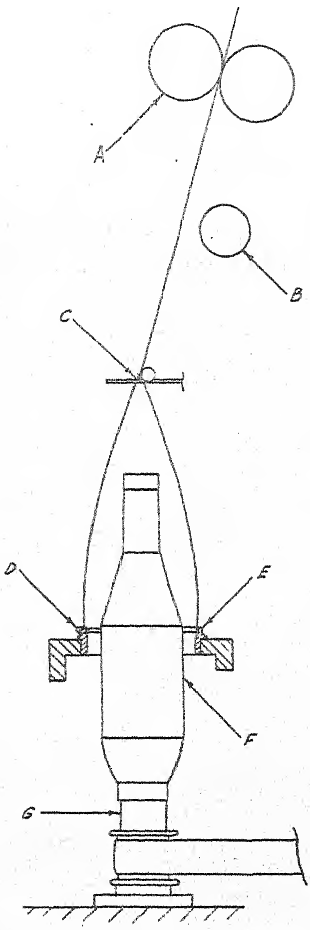


Fig. 2

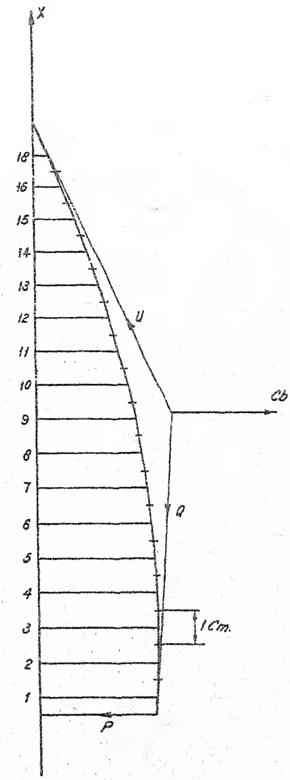


Fig. 4

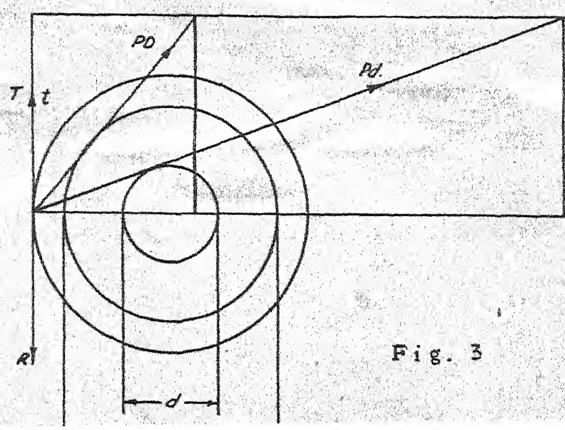


Fig. 3

diameter D and the small diameter d respectively. If these tensions are resolved into tangential and radial components, then the tangential components T and t which balance the traveller resistance, must be equal and constant. In order that this may be so then the tension Pd must be considerably greater than tension PD i.e. tension is higher when winding on smaller diameters.

Due to the rapid rotation of the length of yarn between the guide eye and the traveller, centrifugal force causes the yarn to form a balloon,(see Fig. 4) of such a shape that the resultant centrifugal force Cb is balanced by the tensions just below the guide eye, U and just above the traveller Q. The force P is reduced somewhat by friction as the yarn passes through the traveller, the reduced force being equal to Q. Similarly a portion of the tension U is absorbed by friction at the guide eye, the remaining tension X being the force that imparts considerable stress to the unspun roving as it emerges from the delivery rollers.

Although this explanation is simplified to a degree, it is obvious that all tensions in the yarn from the delivery rollers to the bobbin are dependent to a large extent upon the tension P and though they may not vary in the same proportion as P they change considerably as the winding diameter varies.

In order to maintain a constant tension it is necessary, therefore, to have two superimposed speed variations in the drive:-

(1) As the ring rail rises and falls to build up the nose of the cop a cyclic speed variation or "chase" is required to allow for the change in winding diameter.

(2) As the rail traverses gradually to build up the cop from base to top an altered "base" speed is needed to allow for taper in the bobbin and the redistribution of forces due to the changing balloon length.

Scope of the investigation.

The particular investigation which is the main subject of this report, was carried out on a 200 spindle frame manufactured by Messrs. Asa Lees, variable speed drive being provided by a three phase, brush shifting commutator motor with a built in spinning regulator, manufactured by Siemens.

The purpose of the investigation was to ascertain:-

(1) Whether the variable speed controls fitted to the machine were giving the desired effect in maintaining uniform tension.

(2) What was the optimum speed and the percentage speed variation for yarns of different counts and different physical condition, in order to maintain production consistent with high standard of quality

(3) Whether an increased production could be obtained by changing the existing state of adjustment of the starting speed, or by variations in the base and chase speed.

Condition of the Machine

The machine had been designed originally for belt drive and was later modified, so that the variable speed motor is now coupled directly to a main shaft. From this shaft the drive is taken by two Renold's chains to two tin rollers and thence by tapes to the spindles and by cords to the false twist respectively. From the end of the same shaft a pinion drives through a series of spur reductions to the bobbin feeds, drafting rollers etc., and through a worm reduction to the main heart cam that actuates the periodic ring rail movement (see Figs. 5 and 6)

A crank on the heart cam shaft actuates the ratchet mechanism to provide for progressive lift of the ring rail. The basic and periodic cams in the spinning regulator are driven from the ratchet wheel shaft and the heart cam shaft respectively. The motor is provided with a "starting" speed adjustment i.e. any desired speed level can be selected and upon this level the basic and chase speeds are superimposed by adjustable regulator settings (see Fig. 7)

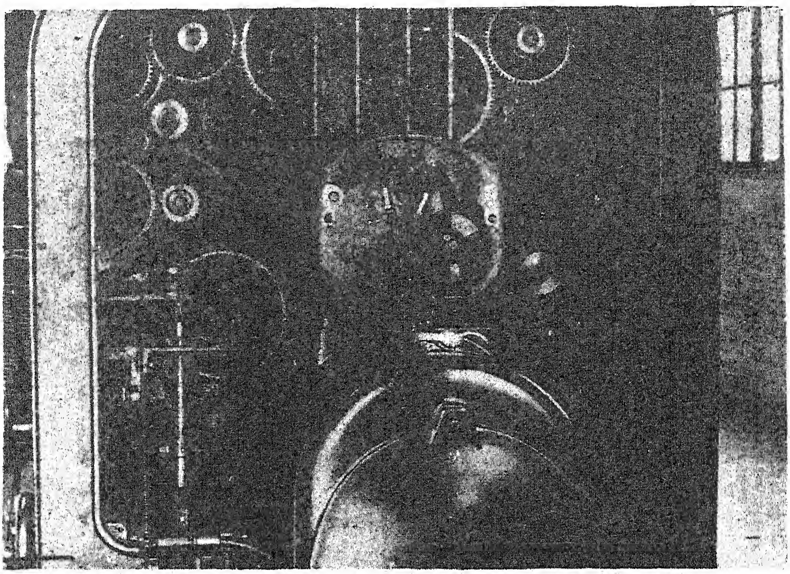


Fig. 5.- Motor, regulator and headstock of frame.

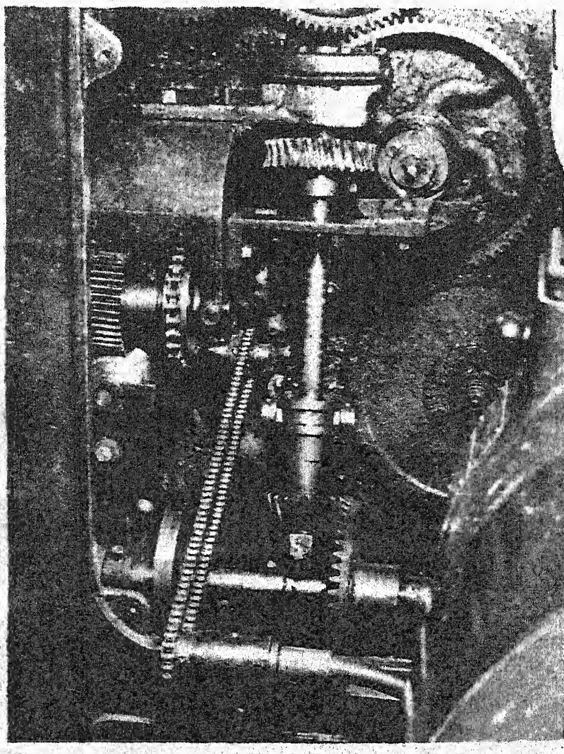


Fig. 6.- Worm and bevel drive to main cam chain drive to base cam on regulator and worm drive to chain for progressive lift.

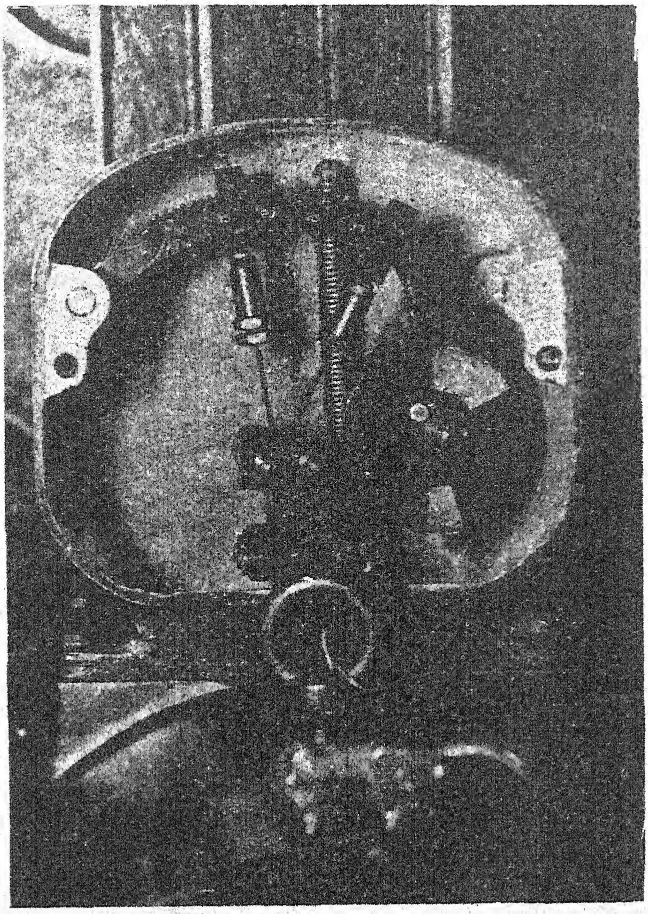


Fig. 7.- Regulator.

Although the machine had been running constantly over the war years with little chance of time off for major repairs, its mechanical condition was reasonably good for normal spinning operations. However, in order to ensure consistent results, and to overcome weaknesses inherent in the design, it was thought desirable thoroughly to examine the machine and to eliminate as many possible sources of discrepancy as could be found. Without entering into a detailed account of modifications and adjustments, the following is a summary of the main points given consideration:-

Possible causes of trouble.

(1) Slackness in speed control drives to regulator.
(2) Frayed wire control cables in spinning regulator. It was found desirable to fit new cables and to design special cable end fittings to prevent chafing and uneven stresses in the flexible wire ropes (see Fig. 7)
(3) Wear in rail lifting equipment. The heart cam was originally of cast iron with a hardened steel insert at the point of maximum displacement. Wear on either side of this insert was causing very uneven ring rail movement and the cam was replaced by a solid steel case-hardened cam. Heavy stresses at this point had caused general wear and flexing of

the worm reduction gears, bearings and brackets, the resulting lost motion being made good by redesign of brackets, renewal of bearings and shafts etc. It is interesting to note that a later design of this frame from the same manufacturer had these details modified and improved.

(4) In order to minimize stresses on the lifting mechanism the ring rail assembly was checked and adjusted for the following points:- Levelling of ring rail; freedom of movement of lifter rods; counter-weighting of ring rail; cleaniness and freedom of movement of lifter and counter weight chains and pulleys; alignment and security of brackets etc. The impression gained was that a multiplicity of apparently minor discrepancies can result in a considerable restriction to freedom of movement of the ring rail and attachments resulting in a "heavy" and uneven drive.

(5) Concentricity of spindles with rings.

(6) Correct seating of rings in ring rail.

(7) Guide eye rail checked for levelling and freedom of movement. Concentricity of guide eyes with spindles and rings.

(8) Chain drive idlers badly worn. These were rebushed as in the original design but due to the high speed and load carried on plain bearings further trouble occurred. Idlers are now being mounted on double row angular contact ball bearings.

Recording of variation in spindles speed.

In order that the speed range could be graphed and analysed it was decided to design and construct a recording tachometer of simple type. In order to eliminate calculations involving ratios of non-positive tape drives etc. and to simplify the mounting of the device, the tachometer head was mounted directly on the spinning spindle. Details of this instrument are shown in Fig. 8 and Figs. 9 and 10. The head employs a Venner Type synchronous motor fitted with minature ball races. The head assembly is mounted on a tapered spindle of similar dimensions to a normal spinning spindle and may be substituted for any spindle on the frame. The head does not interfere in any way with the normal operation of the frame, being clear of the ring rail when the latter is at its highest position, and capable of being driven at speeds as high as 7,500 r.p.m. The head is connected to an electronic unit and thence to a graphic recorder.

Electronic Unit and Recorder.

The purpose of the electronic unit is to convert the output of the "Venner" motor, driven as a generator, into a D.C. current,, whose value is dependent only on the speed of the motor, and to record the output on a permanent graph in terms of r.p.m. Special precautions are taken to make the unit independent of the amplitude of the generator voltage and fluctuations in main voltage.

The equipment consists of six valves with their power supply (see Fig. 11). The first valve works as a straight voltage amplifier, and is conventional with the exception that large decoupling condensers are used to accommodate the low frequencies obtained from the Venner motor. The next valve (V2) is a limiter, and is biased to about -30 volts, so that only the positive peaks are passed on (and amplified). This inhibits the amplification of any noise, microphonics or hum which may be present, and hence prevents them from operating the recorder and giving spurious readings.

V3 is a pentode with no cathode resistor and a low plate load, and works as a clipper valve, squaring up the waveform by swinging the plate current from cut-off to saturation. The steepness of the sides of the waveform is increased by running the screen at a fixed voltage of +150 volts obtained direct from the power supply.

There is thus produced a square wave of constant amplitude irrespective of voltage input to the circuit from the Venner (above a low minimum value), but varying in frequency in accordance with the variation in spindle speed.

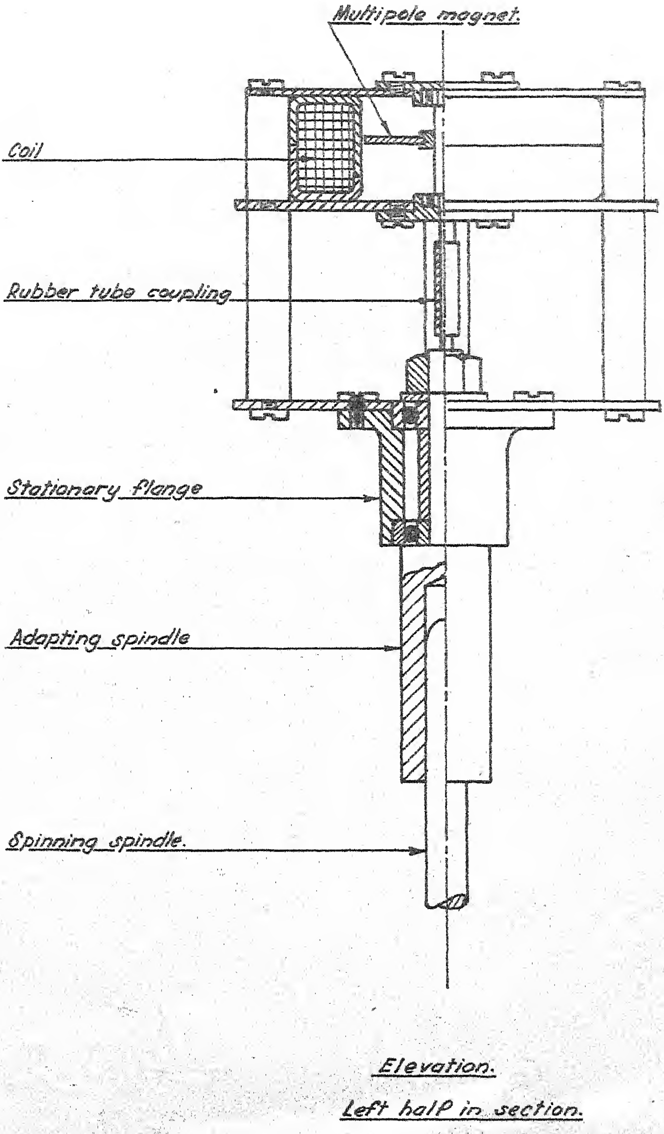
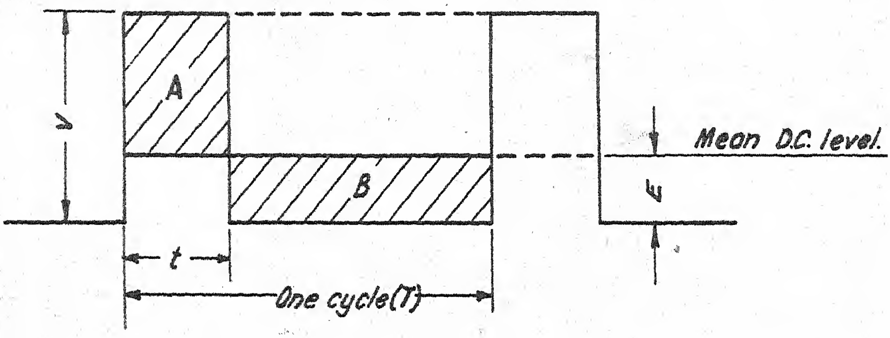


Fig. 8.

This square wave is then passed through a low time constant network consisting of $15 \mu F$ condenser and $100,000\ \Omega$ resistor, which differentiates the waveform, giving positive and negative "pips" of constant amplitude and duration, but vary in frequency. These are applied to the grid of V4a, which being run with no cathode resistor, passes the negative pips only, which appear as large positive pips across the plate load of the valve.

These positive pips are handled by the diode V5 and its associated circuit to give a positive D.C. voltage at its output which is proportional to the frequency of the applied voltage. The manner of operation of this part of the circuit is identical to that of an ordinary positive-peak reading diode voltmeter, with the exception that in this case the diode is "upside-down" and therefore measures the peak value of the excursion of the voltage in a negative direction from the mean (D.C.) level. That this gives a value proportional to the frequency is easily seen by considering the voltage as a square-wave V of small duration t, the period of the voltage being T $\left(= \frac{1}{\text{freq.}}\right)$

Representing one cycle graphically, we have:



Now the mean D.C. level is found when area A (area above the level) is equal to area B (area underneath the level), i.e. when

$$(V - E)\, t = E\,(T - t)$$
$$Vt = ET$$

or peak negative voltage E = Vtf. (since $f = \frac{1}{T}$).

Although we have considered the simple case of a square wave, it can be shown that a differentiated wave, which is what we are handling in practice, also gives the result that

Peak negative voltage is proportional to the frequency.

This positive D.C. voltage proportional to frequency derived from V5 is applied direct to the grid of V4b, the bias on which can be varied by means of the 1 megohm potentiometer so as to set the value of voltage from V5, and hence the frequency, at which V4b conducts, and at which the recording milliammeter operates.

The maximum grid voltage, or frequency, to give full-scale deflection on the meter is determined by the setting of the 10,000 ohm potentiometer in the plate load of V4b.

Hence it can be seen that the instrument will record variations in spindle speeds between two values of speeds which can be set at will.

The power supply is conventional, and need not be discussed.

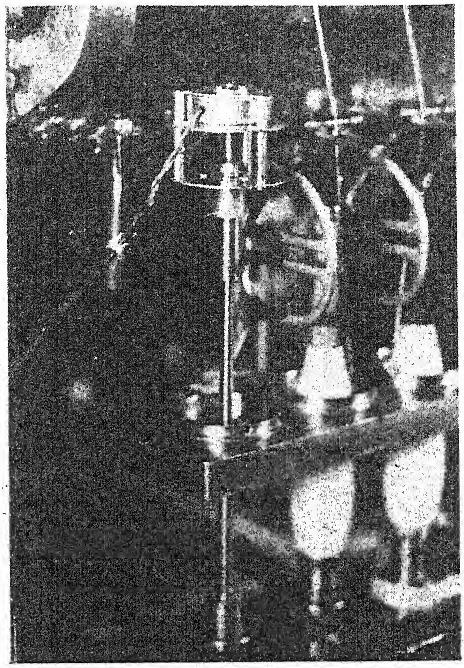


Fig. 9.- Head for recording tachometer shown on end spindle.

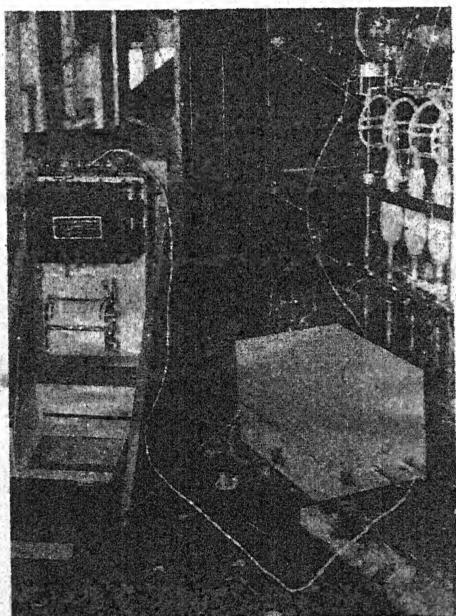


Fig. 10.- Recording tachometer in operation in No. 1 frame.

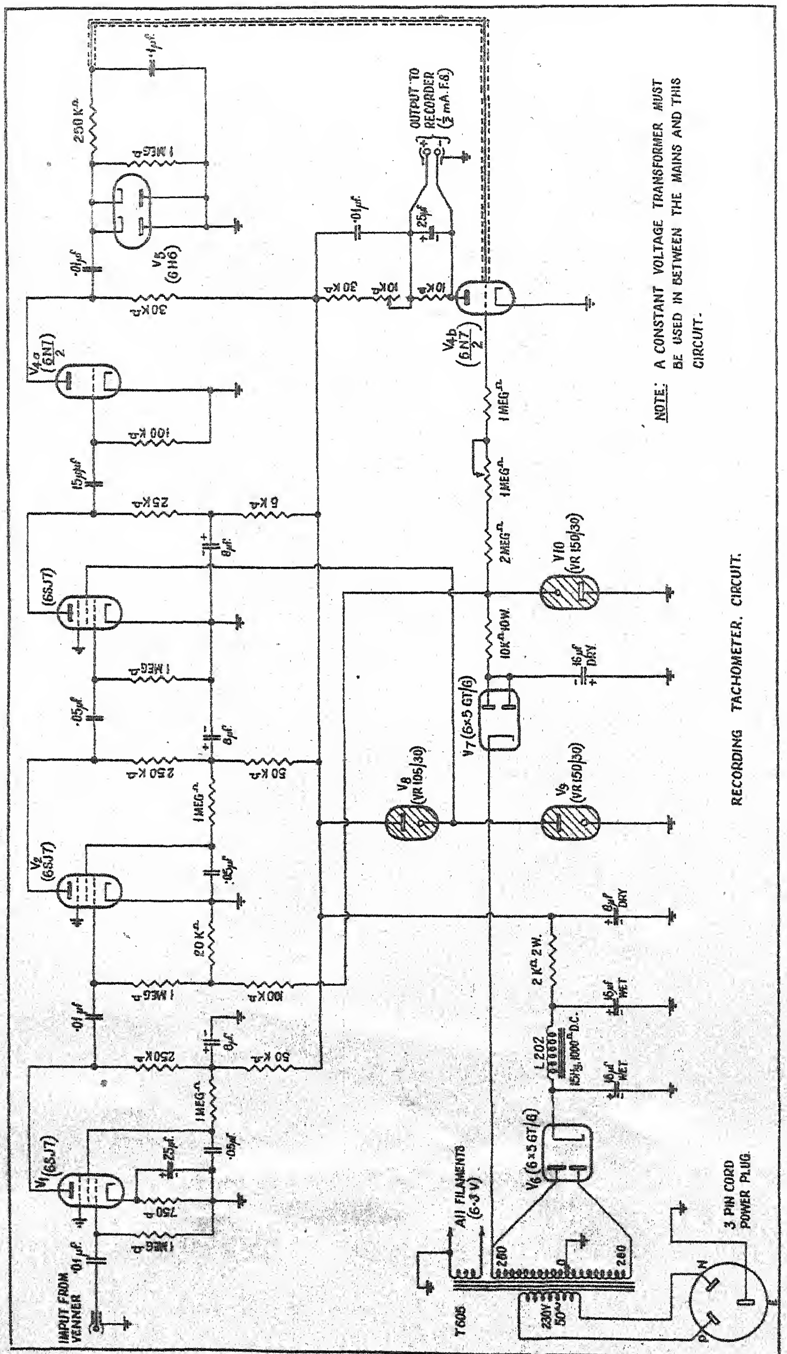

RECORDING TACHOMETER. CIRCUIT.
NOTE: A CONSTANT VOLTAGE TRANSFORMER MUST BE USED IN BETWEEN THE MAINS AND THIS CIRCUIT.
OUTPUT TO RECORDER
INPUT FROM VENNER
3 PIN CORD POWER PLUG
All FILAMENTS (6·3 V)

Fig. 11

Recording Unit.

The only recorder available consisted of an 0 - 0.5 m.a. - meter with a long pointer arm mounted vertically. On the lower end of the arm was pivoted a siphon type pen with a counterweight adjustable so as to control the pressure between the pen and the chart paper which passed underneath at a constant speed (approximately 6 in. per hour). The siphon was arranged so that one arm always dipped into ink in a channel running the full width of the paper.

The limitations of this type of recorder and the effect of voltage fluctuations on the speed of the spinning machine are now considered; selected tachograms obtained during the progress of complete doffing will serve to illustrate the following points:-

The diagram Fig. 12, although taken more as a test of the tachometric equipment during the early development stage shows some interesting points. The variation in base speed and the cyclic speed variation are both evident but most striking in this case is the "down time" of the machine caused by the necessity for replacement of rovings as the spools become empty. Some trouble was experienced at this stage by excessive lag in the pen movement and this was later reduced to a satisfactory limit by widening the scale of the recorder and by paying particular attention to details of pen adjustment.

Referring to Figs. 13 and 13a, the heavily inked part A shows the effect obtained when either the ink level in the channel is too high or the counterweight is badly adjusted so that the pressure between pen and paper is high. Both of these causes tend to prevent movement of the pen and so give rise to "lag" or a reduced amplitude of swing, and also produce too great an ink flow so that spaces between cycles become filled in.

The points marked B are examples of small irregularities on the surface of the paper preventing the free movement of the pen to the end of its swing, while the points marked C show how fidelity of reproduction is much reduced if the amplitude of swing is small, because the driving force from the milliammeter is then insufficient to drive the pen against the paper friction and the inertia effect of the ink bath. A potentiometer type of recorder, if available, would have completely overcome these defects, as such a recorder has a power driven pen and does not rely for its operation upon the limited force produced by a small current.

In spite of these difficulties quite accurate tachograms were recorded, check readings or calibration being obtained by means of a "Strobotac". Before being put into operation the tachometric equipment was tested for possible errors due to main voltage fluctuations and was found to be independent of such variations as are likely to be encountered. Hence any abnormally high and low crests or troughs in the tachograms (apart from paper irregularities), can be attributed to actual changes in spindle speeds caused by the effect of mains fluctuations on the driving motor. Several examples of this effect are marked D in the accompanying tachograms.

Yarn Tension.

As the main object of this investigation was to determine whether uniform tension was being obtained during the cycle, considerable thought was given to the measurement of this tension. Problems exist in the way of direct measurements owing to the twist which is being put in the fibres by the spinning process. Experimental work is at present being carried out on a tension recorder on the "electrolimit" principle, and it is hoped by its use to check on the results obtained by the photographic method that was employed, and to provide a simpler and more direct method of measuring tensions.

As previously explained, the yarn forms a balloon such that the centrifugal force balances the tensions at the top and bottom of the balloon. If a photograph of a balloon is taken, the outline so obtained can be treated as the funicular polygon of the centri-

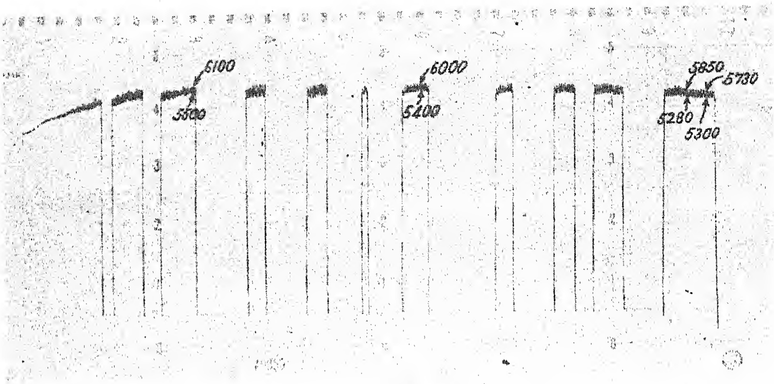


Fig. 12

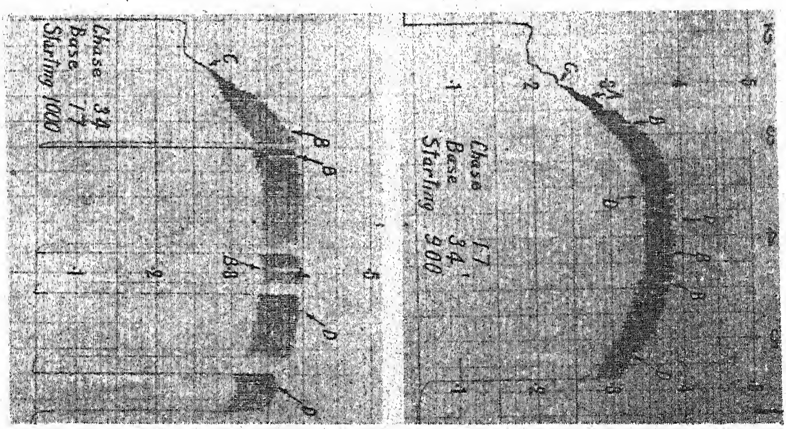


Fig. 13

fugal forces acting on the yarn divided up into separate elements, i.e. the total centrifugal force can be calculated and the tensions U and Q determined. From a series of photographs taken at various stages (Fig. 14) the changes in tension during a complete doffing can be determined.

The method of determining tensions and the calculations necessary for one particular balloon are given in more complete detail as follows:-

The balloon profile shown in Fig. 4 is plotted full size from the photograph and then divided into elements of 1 cm. length. From the centre of each element the radius is drawn in and measured. Since centrifugal force is proportional to radius the sum total of the radii of all elements is a measure of the total centrifugal force. In this case Cb is represented in Fig. 15 by BC, 43.72 cm. long. From B and C lines BA and CA are drawn parallel to the tangents at the ends of the balloon. Then BA and CA are measured and to the same scale as for centrifugal force these give the tensions Q and U respectively.

In this case BA = 81.36 cm. and CA = 89.92 cm. A weight check on the yarn showed the count to be 17.398 skein (Yorkshire count). Weight of 1 cm. (or one element of balloon.) = 0.0011137 g.

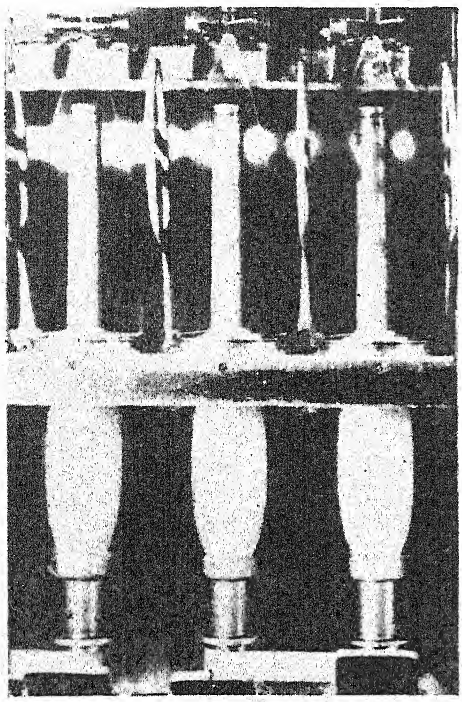


Fig. 14.- Typical balloon profile.

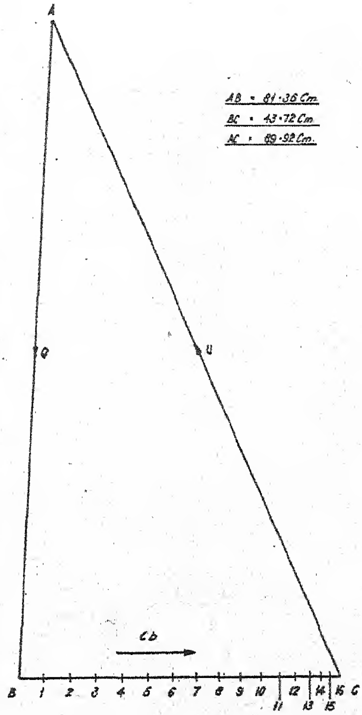


Fig. 15

Centrifugal force

$$= \frac{W}{g} \times R \times \left(\frac{\pi N}{30}\right)^2 \text{ g.}$$

where "W" = weight in g.
"g" = 9.81 metres per sec.^{2}
"R" = radius in metres.
"N" = r.p.m.

Element No. 5 had a radius of 3.41 cm. and N was 5,660 r.p.m.

Centrifugal force of element =

$$\frac{0.001137 \times .0341}{9.81} \times \left(\frac{\pi \times 5,660}{30}\right)^2$$

$$= 1.36 \text{ g.}$$

Scale for forces:- 3.41 cm. = 1.36 g.
Therefore tension U represented by 89.92 cm.

$$= \frac{1.36 \times 89.92}{3.41}$$

$$= 35.86 \text{ g.}$$

and tension Q represented by 81.36 cm.

$$= \frac{1.36 \times 81.36}{3.41}$$

$$= 32.45 \text{ g.}$$

The results of a series of photographs taken at various stages during a doffing both with the ring rail up and with the ring rail down, are listed in Table I and plotted in Figs. 16 and 17, while in Fig. 18 is the corresponding tachogram. It is to be noted that when the balloon is very short irregularities in the yarn cause twitching of the balloon. It is also rather difficult to determine tangents to the balloon at this stage and the last values (with the ring rail up) are the averages of two adjacent balloons. Also when winding on the large diameter at the base of the cop the balloons in this case were beating against the balloon separators so that the profiles had to be corrected to a shape estimated to be that obtaining without separators.

In spite of these difficulties the results obtained are believed to be reasonably true indication of the tensions occurring.

It can be readily appreciated that the variation in tension U from a minimum of 21.34 g. to a maximum of 56.31 g. must produce a very uneven yarn, as the tension X under which twisting takes place varies with U and is probably only about 10 per cent. smaller.

It is to be noted that the tension Q, and therefore the winding tension P, did not vary extremely from the small to the large diameter at any given position on the cop. With this fact in mind the progressive reduction in Q towards the top of the bobbin was substantiated by the appearance and "feel" of a finished cop, the nose to some extent being soft and loose compared with the base. During the test the regulator was set to obtain maximum variation in both "base" and "chase" speeds. Under normal conditions the regulators could be set by trial so as to obtain a cop that felt more evenly firm but such a method of regulation can be at best, only a very rough approximation; regulation by judgment of even firmness can only be very misleading and large discrepancies in spinning tension could still be present, a more sound knowledge of the changes in tension occurring, being necessary to obtain correct regulation.

The Determination of Corrected Speed.

The centrifugal force of the yarn forming the balloon, the centrifugal force of the traveller and therefore, the friction of the traveller, are proportional to the square of the speed. Since all tensions in the thread are in equilibrium with these forces it follows that the tensions vary as the square of the speed. This is borne out by the fact that when the speed changes say at a given position of the ring rail, no visible change occurs in the profile of the balloon. It is possible, therefore, to calculate the speed required at any particular stage to give a desired tension, or if a constant tension is required the necessary speed diagram can be determined.

Attention can be directed to maintaining constant either the tension U or the tension Q. In this case it was decided to maintain a constant tension at the top of the balloon as this ensures twisting at constant tension, and therefore a higher standard of quality. This method also tends to minimize breakages so that high production can be obtained; while winding tension, although varying to some extent will be within the limits necessary to ensure reasonably regular winding. The selection of 45 g. as the constant tension desired in this case was governed by the fact that only a reasonable number of breakages were occurring, and the selection of any higher value would probably result in the overstressing and breaking of every weak place in the roving. As a point of interest, the results of strength tests on a similar yarn but of slightly higher count were used to estimate the ratio of yarn strength to spinning tension U and gave a figure of 6.55. This may give the impression that spinning tension could be taken much higher but it must be remembered that the roving emerging from the delivery rollers is untwisted and therefore, weak compared with the finished yarn.

A typical case of speed correction is as follows: Referring to previous calculations, a tension U of 35.86 g. was produced by a speed of 5,660 r.p.m. whereas a tension of 45 g. is desired.

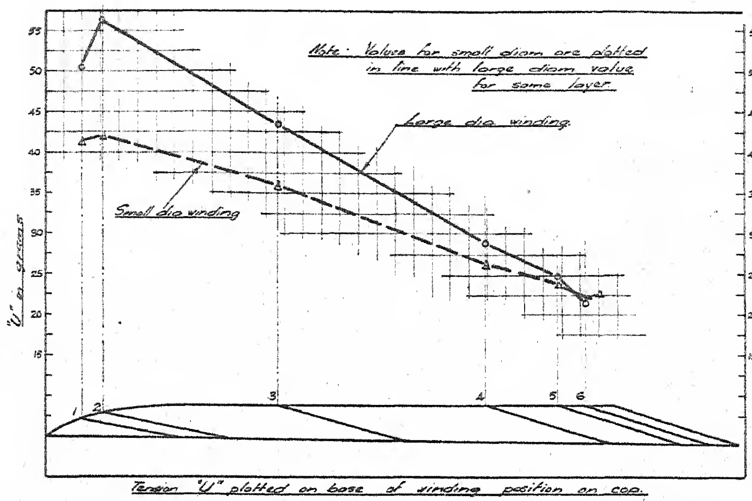

Note: Values for small diam are plotted in line with large diam value for same layer.
Large dia winding.
Small dia winding
"U" in grams
Tension "U" plotted on base of winding position on cop.

Fig. 16

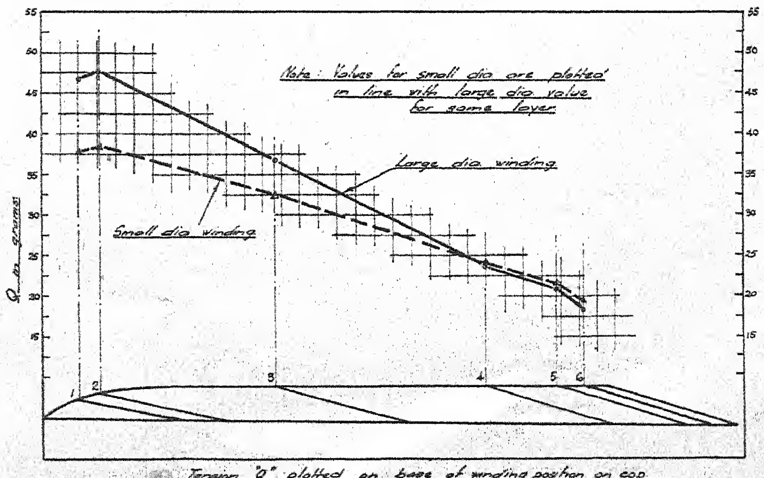

Note: Values for small dia are plotted in line with large dia value for same layer
Large dia winding
Small dia winding
Q in grams
Tension "Q" plotted on base of winding position on cop

Fig. 17

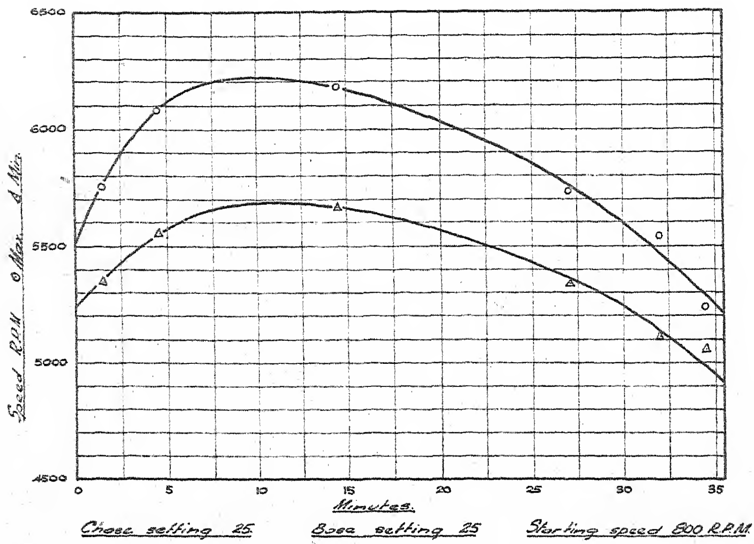

6500
6000
5500
5000
4500
0
5
10
15
20
25
30
35
Speed R.P.M. ○ Max. △ Min.
Minutes.
Chase setting 25
Bose setting 25
Starting speed 800 R.P.M.

Fig. 18

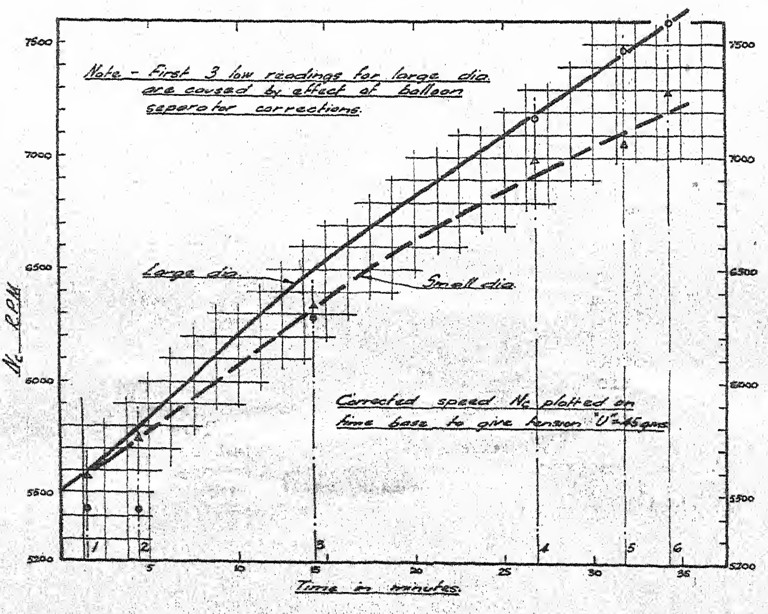

Note - First 3 low readings for large dia. are caused by effect of balloon seperator corrections.
Large dia.
Small dia.
Corrected speed N_c plotted on time base to give tension "U"=45 gms.
N_c R.P.M.
Time in minutes.
7500
7000
6500
6000
5500
5200
5
10
15
20
25
30
35
1
2
3
4
5
6

Fig. 19

If Nc is the corrected speed then

$$\frac{Nc^2}{N^2} = \frac{45}{35.86}$$

i.e.

$$Nc = \frac{5,660^2 \times 45}{35.86}$$

$$= 6,340 \text{ r.p.m.}$$

All tensions at the top of the balloons were treated in this way and the results are listed in Table I and plotted in Fig. 19.

It is interesting to note that the speed diagram is plotted on time base, whereas if corrected speeds are plotted on a base of balloon lengths the results approximate to a straight line with an equation:-

Corrected Speed r.p.m. = 8,505 - L × 129.86

where L is balloon length in cm.

A balloon length speed plot when winding on small diameters where there was no interference from the balloon separators is shown in Fig. 20.

The boundary lines of the speed diagram in Fig. 19 were based upon a consideration of balloon length, restriction of ring rail movement when forming the cop base and movement of the lappet rail, and compare favourably with diagrams calculated for spinning cotton on similar machines.

The small variation required in periodic speed as compared to the large change in base speed is due to the low ratio between small and large diameters, (approximately 2, half way up the bobbin). In cotton spinning the usual practice is to reduce the speed somewhat (from theoretically calculated values) when forming the base and towards the end of the doffing. The reasons for these reductions are respectively:

(1) When forming the base with a large balloon it is believed that extra tension is caused by a skipping motion of the traveller.

(2) At the end of the doffing the balloon is so short and inelastic that any discrepancies in the yarn cause a twitching effect that cannot readily be absorbed by the balloon and tensions may momentarily be far greater than their normal values.

Adjustment of Regulator Settings.

When an attempt was made to adjust the regulators so that the tachograms obtained would conform more nearly to the ideal diagram, it was found that a speed restriction stop in the motor brush movement limited the maximum spindle speed obtainable to a range of 6,100-6,440 r.p.m. the exact value depending upon the mains voltage. With motor "starting" speeds of the order of 900 to 1,000 r.p.m. and with large settings of the base regulator, it was found that the top part of the diagrams obtained was "clipped" to the level mentioned above. This effect is shown in Fig 21 where average boundary lines are drawn through the plot points of several tachograms and "Strobotac" check points.

A reduction in starting speed or in the base regulator setting had the effect of lowering the minimum speed boundary, but left the central portion of the maximum speed boundary line at the same level i.e. tending to go higher on the diagram but being clipped by the motor speed restriction. This produced the apparently incongruous effect of a reduction in "starting" speed and/or base variation bringing about an increase in chase speed variation.

The diagram in Fig. 19, although it would probably not have resulted in excessive thread breakages, could therefore have been obtained only by increasing the maximum spindle speed. Any change in the ratio of the drive to the spindles however would in turn bring about the added complication of having to change the drive ratios of all other sections of the machine.

TABLE I.

Photograph number	Element number	Radius of element (cm.)	Speed (r.p.m.)	Centrifugal force of element (g.)	Sum total of radii (cm.)	Length side (B.A.cm.)	Tension "U" at top of Balloon (g.)	Length of side (S.A.cm.	Tension "Q" at bottom of Balloon (g.)	Corrected Speed for "U" - 45 g. (r.p.m.)
RING RAIL UP										
1d	7	4.1	5,350	1.4609	71.16	116.16	41.39	105.60	37.63	5,578
2d	6	4.3	5,550	1.6489	69.96	109.36	41.94	100.28	38.45	5,749
3d	5	3.41	5,660	1.3600	43.72	89.92	35.86	81.36	32.45	6,340
4d	5	3.0	5,330	1.0611	29.68	74.08	26.20	67.24	23.78	6,985
5d	4	2.83	5,110	0.9200	23.24	72.52	23.57	66.12	21.49	7,059
6d	4	2.73	5,050	0.8667	21.56	57.84	21.62	50.76	19.38	7,285
6d	4	2.63	5,050	0.8350	21.20	78.32	Average	71.32	Average	Value from Average U
RING RAIL DOWN										
1d	10	5.47	5,750	2.2516	108.00	122.60	50.46	113.32	46.65	5,429
2d	12	5.41	6,075	2.2486	106.40	122.56	56.31	103.40	47.51	5,430
3d	9	5.01	6,170	2.3744	83.72	91.60	43.41	77.16	36.57	6,282
4d	6	4.18	5,730	1.7086	55.36	70.32	28.74	57.76	23.61	7,169
5d	5	3.76	5,540	1.4367	43.80	64.84	24.78	54.44	20.80	7,466
6d	5	4.03	5,230	1.3724	44.48	62.64	21.34	53.84	18.33	7,594

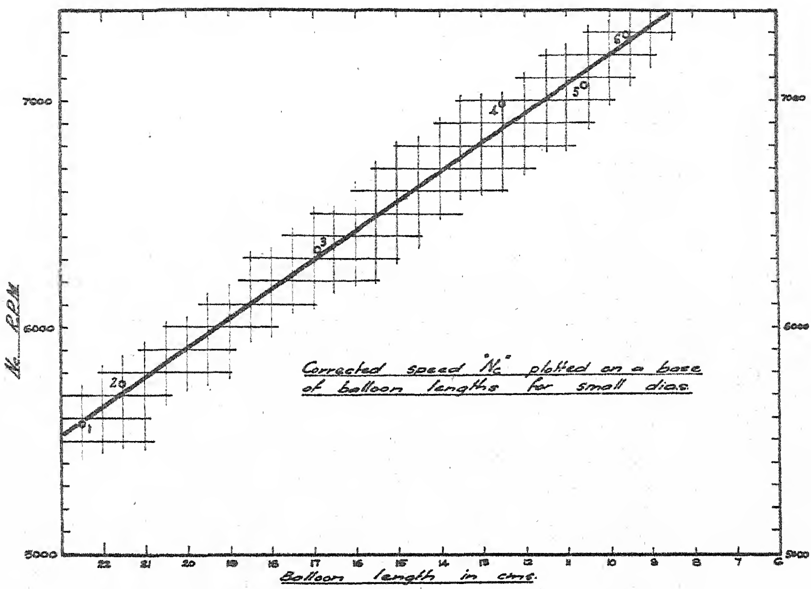

Nc R.P.M.
Corrected speed "Nc" plotted on a base of balloon lengths for small dias.
Balloon length in cms.

Fig. 20

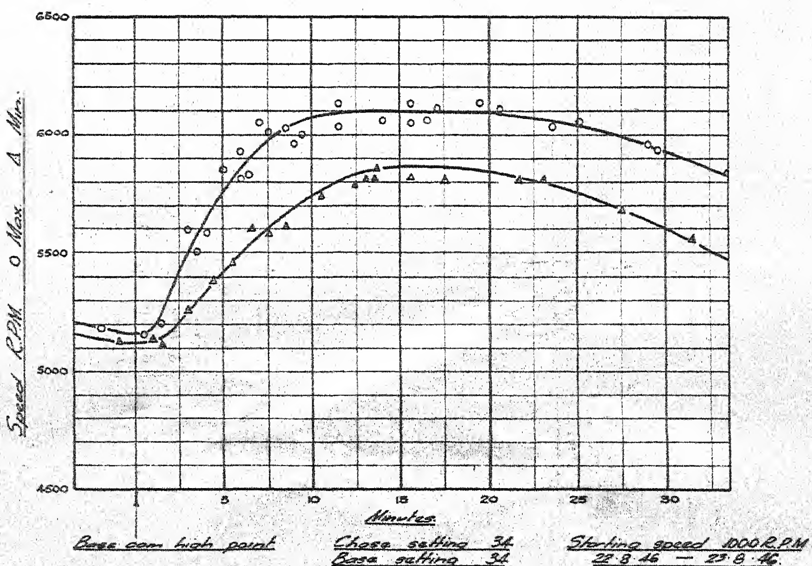

Speed R.P.M. O Max. Δ Min.
Minutes
Base cam high point
Chase setting 34
Base setting 34
Starting speed 1000 R.P.M
22.8.46 — 23.8.46

Fig. 21

To overcome these difficulties the ideal diagram in Fig. 19. was replotted as in Fig. 22 to give a constant tension U of 35 cm. On the basis of a maximum speed of 6,200 r.p.m. being obtainable, this meant that some reduction below the ideal was inevitable towards the end of the doffing, this reduction however , serving to compensate for excessive momentary tensions due to "twitching" effects with short balloons.

Fig. 23, shows the results of taking a previous tachogram and extending the horizontal scale to represent a change in the ratio of the drive to the base cam from 17:17 to 17:38 (standard chain drive sprockets).

With a starting speed of 900 r.p.m. some degree of correlation with Fig. 22 is immediately apparent, and closer correlation could be obtained by adjustments to the regulator settings. It may be seen therefore that practical aspects of the problem and limitations in the machine itself modify to some extent the ideal conditions aimed at, but nevertheless an investigation from a theoretical point of view can be helpful as a guide to obtaining efficient utilization of the machine.

Simplification of calculations.

It will be appreciated that a considerable amount of calculation is necessary in proceeding step by step as previously described. These calculations can be shortened to some extent by combining individual steps into a simplified overall formula. This simplification is effected as follows:-

Referring again to Figs. 4 and 15

Centrifugal force of one element.

$$= \frac{W}{g} \times R \times \left(\frac{\pi N}{30}\right)^2$$

$$\text{Total Cb} = \frac{W}{g} \times R \times \frac{(\pi N)^2}{30} \times \frac{\text{sum of radii}}{R}$$

$$\text{Tension U} = \frac{\text{Cb} \times \text{AC}}{\text{BC}}$$

$$\text{and AC} = \frac{\text{BC} \times \text{sine B}}{\text{Sine A}}$$

$$\text{Tension U} = \frac{W \times \pi^2 \times N^2 \times \text{sum of radii} \times \text{sine B}}{g \times 900 \times \text{sine A}}$$

This can be further simplified by inserting skein count instead of W. The tension U then equals

$$\frac{\text{sum of radii} \times N^2 \times \text{sine B}}{\text{skein count} \times \text{sine A} \times 4,616,600}$$

where the sum radii is in cm.

N= r.p.m. and skein count is the Yorkshire system of 256 yd. skeins to the pound.

Corrected speed can also be calculated by a simplified formula:-

If Uc is the desired tension at the top of the balloon then

$$\text{Nc} = \sqrt{\frac{N^2 \times \text{Uc}}{U}}$$

$$= \sqrt{\frac{\text{Uc} \times \text{skein count} \times \text{sine A} \times 4,616,600}{\text{sum of radii} \times \text{sine B}}}$$

These formulae are applicable to any machine i.e. if a balloon is photographed and the speed recorded it is necessary only to find the sum of the radii when the balloon is divided into elements of 1 cm. length, measure the two angles A and B, and then insert the appropriate values in the formulae to find U, or to determine Nc for any desired tension.

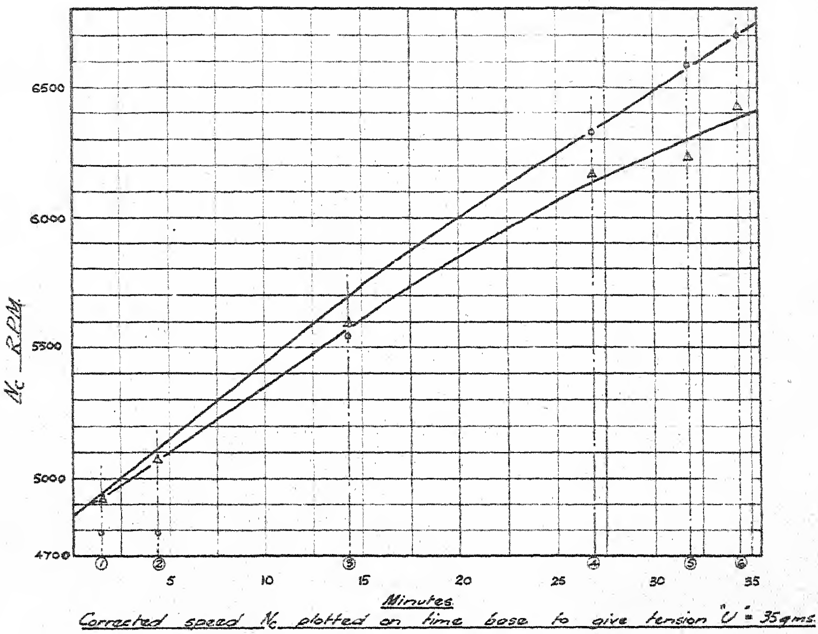


Fig. 22

CONCLUSIONS.

(1) The use of a constant speed drive must result in considerable changes in spinning tensions. The speed must be low enough to prevent excessive breakages at the base and towards the end of the doffing. For the remainder of the cycle considerably higher speeds can be utilized.

(2) For any one layer of winding at constant speed the tensions are higher for the small diameter than for the large diameter: and for any one diameter the tensions fall progressively from the base to the top of the bobbin.

(3) Variable speed driving can do much towards obtaining constant tension and increased production, but the extent of the variation required must be carefully determined and due regard must be given to the practical limitations of the ring spinning process, i.e.a theoretical ideal diagram must be modified to allow for such effects as traveller skipping and balloon twitching. Failure to obtain correct regulation means that the purpose of variable speed drive, to maintain constant tension, is not fully realized.

(4) In the selection of drive ratios to a frame used for a particular range of counts due regard must be paid to the highest spindle speed likely to be required. For maximum production it should be possible to obtain tensions approaching the limit set by excessive breakages; and the spindle speeds necessary should be obtainable while the full range of regulation is still available without restriction from maximum motor speed limits.

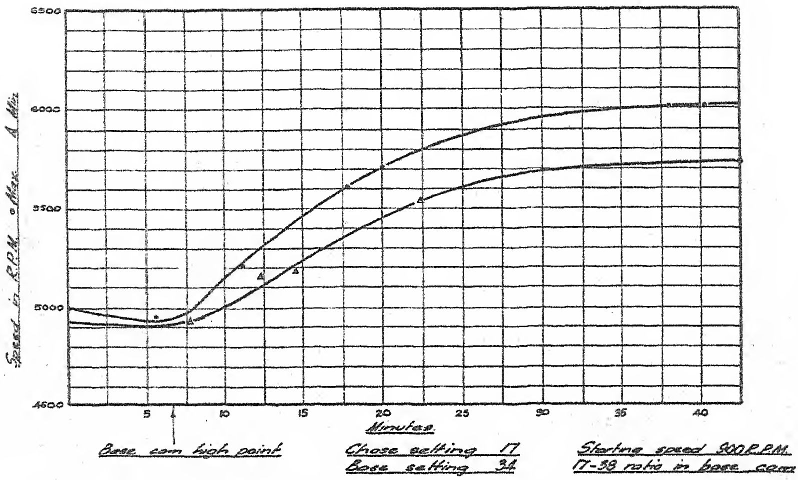


Fig. 23

(5) Speed regulation determined by the appearance and "feel" of a cop is not satisfactory as discrepancies in tension could still be present and a more thorough knowledge of tension variations is necessary.

(6) The large number of variable factors such as traveller weight, skein count, cop dimensions, and general characteristics of individual frame design, preclude the possibility at this stage of determining speed variations by a simple formula and each case must be treated on its own merits.

(7) The photographic method of determining tensions produces results more accurate than might be expected at first glance, but the method has limitations. The amount of work involved is large, and small discrepancies may occur in drawing tangents to plotted balloon profiles. Again, the photographs cannot show the effect of air resistance in producing an "S" curve in the balloons in a plane at right angles to the photographed plane. Centrifugal force is however, large compared with air resistance, and the increase in tension due to the latter cause accounts for only a small percentage increase in the tensions as calculated.

(8) The effect of balloon guards is indeterminate, but the reduction in balloon size and centrifugal force is probably offset to a great extent by increased drag of the balloon across the face of the guards.

(9) The development of a satisfactory type of direct reading tension recorder would facilitate investigations. Tension variations between the delivery rollers and the guide eye could be determined readily; no factor influencing tensions would be neglected, and many sources of error and a large amount of calculation would be eliminated.

(10) The tachometric head and electronic unit described have reached a very satisfactory state of development. The inherent disadvantages of the milliameter recorder could be overcome in a potentiometric type of recorder, and it is hoped by developing such a unit to obtain a recording tachometer of high fidelity which will have many uses in the textile industry.

COMPOSITION OF NATURAL WATERS OF CANTERBURY AND WEST COAST DISTRICTS WITH SPECIAL REFERENCE TO CHRISTCHURCH ARTESIAN WATER.

BY F.J.T. GRIGG, * DOMINION LABORATORY, WELLINGTON, DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH.

[*Received for publication, 16th April, 1947*]

Summary

The paper is a resumé of investigations relating to the water supplies of Canterbury and the West Coast districts, carried out by the writer or under his direction as Government Analyst at Christchurch, with the addition of a few previously published results for completeness.

In particular, an account is given of the Christchurch artesian supply with respect to mineral constituents, content of dissolved gases, iodine, fluorine, and other minor constituents, radioactivity, and bacteriological conditions. The artesian supply is water of exceptional purity for drinking purposes and for commercial use it is fairly soft and non-corrosive water.

River, lake, and non-artesian well waters are discussed, and an account is given of the mineral waters of the districts.

A table of the mineral content and hardness of the town supplies of Canterbury and the West Coast is given.

All results are expressed in parts per million in accordance with recently adopted practice in New Zealand.

INTRODUCTION

A large number of analyses and investigations of water supplies in Canterbury and the West Coast districts have been made by the writer or under his direction as Government Analyst at Christchurch since 1925. There is an increasing demand for information on these matters, by commercial and other users of water, and as many of the results are buried in departmental reports, the present paper is designed to give an indication of the general character of the waters and to summarize available data. Principal interest, of course, surrounds the Christchurch artesian system which is unique in New Zealand as a water supply, and a major asset to the City of Christchurch.

GEOLOGICAL OUTLINE

Canterbury and Westland are separated by the Southern Alps, which are the source of most of the rivers flowing east and west. The Canterbury Plains extend from the neighbourhood of Amberley in North Canterbury to the dolerite plateau of Timaru in the South, with a length of about 112 miles. The Alps consist chiefly of greywake, a hard siliceous material, formed chiefly out of minerals constituting granite, viz. quartz, mica and feldspar. The plains have been described as river shingle and sand cemented more or less by a ferruginous matrix. The nature of the mountains and the plains is the key to the composition of the mineral constituents of the waters, which are on the whole of low mineralization, with silica and lime as the main components.

CHRISTCHURCH ARTESIAN SYSTEM

The artesian area consists of a belt of country fringing the coast from the mouth of the Ashley River southwards through Kaiapoi, Taitapu, and Ellesmere to the mouth of the Rakaia River. It is about 50 miles long, narrow at the north and south, but reaching a width of about 10 miles at Christchurch.

For a full geological discussion of the origin and structure of beds supplying artesian waters, geological literature should be consulted, but briefly it may be said that the land under Christchurch consists of irregular beds of shingle separated by layers of clay

* Previously Government Analyst, Christchurch.

or other impermeable material such as sand or consolidated beds of gravel. There are also peat beds and some belts of marine shells. The wells vary in depth, some tapping strata near the surface, others reaching a depth of over 700 feet.

OTHER WATER SOURCES

Apart from analyses of waters of the artesian system this paper will include analyses of typical lake, river, and shallow well water (non-artesian) and an account will be given of the mineral waters of the district. It may be stated that Canterbury public water supplies are mainly derived from wells, viz. the supply of Christchurch is wholly from artesian water, and those of Rangiora, Ashburton and Temuka are derived from well water (non-artesian). Timaru, Waimate Geraldine, Kaikoura and Hanmer derive their supplies from river water.

On the West Coast, the Westport supply is stream water, the Greymouth supply is pumped from a well near the Grey river, and Hokitika is supplied from both Lake Kanieri and from a well near the Hokitika River. A summary of the mineral composition of the town supplies is included in this paper.

COMPOSITION OF THE WATERS

(A) *Christchurch Artesian Water.* It is emphasized that waters from various strata and localities vary appreciably in composition and, as industries usually sink their own wells, for commercial purposes an analysis should always be made of the water from the bore to be used. The chemical and bacteriological analyses given will however give a good indication of the quality of the main Christchurch artesian supply. It will be noted that ammoniacal nitrogen and organic matter are absent, total solids are low, and bacteriological condition very satisfactory. Temporary hardness varies from about 40 to 70 parts per million and permanent hardness is usually nil but may be present up to about 20 parts in some cases.

Most of the artesian water is of the excellent quality represented by the chemical and bacteriological analyses, but there are important exceptions, viz. certain waters containing iron and sulphuretted hydrogen, from bores in such areas as New Brighton, Burwood, Kaiapoi, Waikuku Beach, and other diverse localities. (These waters are not recommended for domestic use.) The amount of iron in these cases varies from a trace to 0.5 part per million, and sulphide is in sufficient quantity to be apparent by odour. Presumably such waters arise from beds of peaty material and contact the ferruginous matrix. In areas where these bores are located however good water can generally be obtained by tapping suitable strata, e.g. good potable waters are available at Waikuku Beach and North Brighton from bores quite close to those giving inferior water.

Other exceptions are wells in an area fringing the foot of the Port Hills in the vicinity of the Estuary. Some of these are high in ammoniacal nitrogen and contain angular fragments of volcanic origin. Others contain more mineral constituents and are harder waters.

There are also abnormal waters in the locality of Banks Peninsula which however are probably not artesian.

In the following paragraphs the principal characteristics of typical Christchurch artesian water will be described under the headings indicated:-

(1) Major Organic and Inorganic Constituents:

The following is a typical analysis:-

Smell	Nil
Colour	Nil
	p.p.m.
Nitrites	Nil
Nitrate nitrogen	0.9*
Ammoniacal nitrogen	Less than 0.002
Albuminoid nitrogen	Less than 0.002
Oxygen absorbed in four hours at 80°F.	Less than 0.02
Iron	Nil

*Note:- Nitrates vary considerably according to location (0.1 to 1.2)

Silicate ion (SiO_3)	21
Chloride ion (Cl)	10
Nitrate ion (NO_3)	4
Sulphate ion (SO_4)	4
Sodium ion (Na)	9
Potassium ion (K)	3
Calcium ion (Ca)	21
Bicarbonate ion (HCO_3)	65
Loss due to bicarbonate ion	33
Total Solids at 105°C.	104
pH	6.8

(2) Dissolved Gases

In most well waters the dissolved gases are not in equilibrium with the atmosphere, and the amounts of gases are thus generally different from those present in water saturated with air.

Christchurch artesian waters contain more nitrogen and less oxygen than is present in distilled water shaken with air.

Free carbon dioxide is low in Christchurch artesian water, which is fortunate as this constituent is a major cause of corrosion in pipes and fittings. In this respect the artesian water differs markedly from other well waters of Canterbury which are nearly all high in free carbon dioxide and much more corrosive.

The results of a number of determinations of dissolved carbon dioxide, oxygen and nitrogen are given below with figures for normal saturation for comparison.

The results are in grams per million parts of water.

LOCATION	pH	CARBON DIOXIDE	OXYGEN	NITROGEN
Sydenham (70 ft.)	7.2	3.5	4.6	25.4
St. Albans (160 ft.)	7.4	1.6	6.6	22.4
" " (280 ft.)	7.4	1.0	6.6	21.0
" " (420 ft.)	7.4	1.0	6.6	26.6
Greenpark (350 ft.)	-	-	6.4	24.5
Distilled Water saturated with air at 57°F.	-	-	10.3	16.7

From the above figures it will be noted that oxygen is very considerably lower and nitrogen very much higher than in distilled water saturated with air at the same temperature. The normal balance may be obtained by cascading or spraying the water. The excess of nitrogen and deficiency of oxygen is harmful to fish life, and artesian water should be aerated if used as a supply for fish ponds etc.

(3) Iodine.

Iodine in Christchurch artesian water has been determined by Rogers (1) in 1927, and by R. L. Andrew about 1930. Rogers obtained figures of the order of 1×10^{-9} g. of iodine per cubic centimetre for artesian water, and Andrew's unpublished result confirmed the amount as a very low one.

It has not been possible for the writer to make more complete investigations owing to the large amount of work involved in the determination of traces of iodine, but there is every reason to believe that the iodine content of Christchurch artesian water is low.

(4) Fluorine in South Island waters has been determined in the writer's laboratory by C.F. Denmead (2). The value for Christchurch artesian water is reported as not greater than 0.10 part per million, the probable value being about 0.06 part per million. This is a very low value, and all other waters from Canterbury and Westland with the exception of a few more highly mineralised waters, have given values under 0.20 part per million.

(5) Other Minor Constituents.

Reference has already been made to the presence of iron and sulphuretted hydrogen in certain exceptional strata, but the main strata yield water free of these substances.

No evidence has been obtained of the presence of appreciable amounts of any minor mineral constituents other than those recorded in the analyses quoted, and it appears unlikely that such are present in quantities of importance to industry or public health.

(6) Radioactivity.

Radium emanation was determined by Farr and Florance (3) in 1909, also by the writer and Rogers in 1922, and again by Rogers in 1927 (1). Farr and Florance's values have been expressed in terms of grams by Maclaurin, a typical value for radium emanation being 0.998×10^{-12} g. per cubic centimetre. This value is high for a water of low mineralization and is comparable with that of more highly mineralised waters in Europe. There was no evidence of radium salts in solution, and the dissolved radium itself must be present in very minute quantity.

(7) Bacteriological Analyses.

Since the beginning of 1946 bacteriological examinations have been carried out systematically of the City Council wells supplying Christchurch City. Two wells have been examined each month and the samples have been consistently of good quality The following figures give a typical analysis, together with maximum and mimimum values to date.

		MAXIMUM	MINIMUM
Plate Count on Standard Agar at 37°C.	100	500	10
" " " " " " 22°C.	700	3,000	100
Coliform Organisms	-	-	-
Most Probable Number/ 100 ml.	Nil	-	-

(B) *Well Waters (non-artesian)*

Water can be obtained from wells in most parts of Canterbury Plains and in favourable localities on the West Coast. A typical analysis is given below. It may be mentioned that many of these waters are aggressive owing to the presence of dissolved carbon dioxide in considerable quantity and there is marked evidence of corrosion in fittings and blocking of pipes where wells are reticulated.

In North Canterbury, wells in the limestone country are higher in mineral content and have a high temporary hardness.

The following is an analysis of a typical shallow well water (non-artesian). The locality is Rangiora.

	p.p.m.
Silicate ion	19.8
Chloride ion	6.0
Sulphate ion	2.4
Alkali (as Na ion)	11.1
Calcium ion	12.4
Magnesium ion	3.6
Aluminium ion	1.2
Bicarbonate (as $CaCO_3$)	18.9
Total solids	75.4
Carbon dioxide (free)	12.0
Oxygen	9.0
Iron	Less than 0.02
pH	6.6

(C) *River and Lake Waters.*

There are large numbers of lakes in the mountainous areas, and rivers crossing the Plains. The lakes are mainly snow-fed and are remarkable, as a result, for their low mineralisation. In the glaciated areas the lake waters sometimes contain in a state of very fine suspension, siliceous material which can be removed only partly by ordinary filtration. This suspended material is nearly all silica with a trace only of iron, alumina and calcium.

The rivers in Canterbury are subject to heavy flooding and carry on these occasions large amounts of suspended material, largely inorganic.

On the West Coast the chemical composition of the waters in lakes and rivers is generally similar to that of the Canterbury district, but large amounts of dissolved organic matter are usually present, derived from the luxuriant vegetation of the district. This organic matter colours the water green or brown and renders it unattractive for commercial and domestic use unless treated.

In the vicinity of the coal mines some of the seepage water contains traces of sulphates and is slightly acid, and there are also well waters containing iron. In general however these constituents are absent from West Coast waters.

An analysis of a North Canterbury river water and that of a lake water are given below. The lake water is from Lake Donn (Ashburton Gorge) and is of exceptionally low mineralization.. The analysis in this case is not quite complete as the low mineralization did not permit a full analysis on the amount of sample available.

River Water.	p.p.m.
Silicate ion	23
Chloride ion	8
Nitrate ion	3
Sulphate ion	11
Alkali (as Na ion)	12
Calcium ion	9
Magnesium ion	Trace
Bicarbonate ion	27
Loss due to bicarb. ion	14
Total solids	79
Iron	0.1
pH	6.7

Lake Water.	
Silicate and Alkali	Not determined
Chloride ion	3.0
Potassium ion	Less than 1.0
Phosphate ion	Less than 1.0
Calcium ion	3.0
Iron	Nil
Bicarbonate ion	9.3
Total solids	18
Oxygen absorbed in 4 hours at 80°F.	0.82
Nitrates	Nil

(D) *Mineral Waters.*

Under this heading may be included waters containing more than the normal amount of dissolved mineral constituents usually associated with potable waters or possessing some unusual characteristic.

There are two groups of interest in Canterbury, viz. some sulphuretted waters in North Canterbury, and wells in the vicinity of Lyttelton Harbour, (Banks Peninsula) which are characterized by their content of magnesium salts.

The North Canterbury group include the well known Hanmer water, the hot springs at Maruia and waters from the Upper Hurunui Valley and Culverden. The two latter are of low mineralization only but are both sulphuretted. Analyses of Hanmer and Maruia water are given below. The analyses quoted were made at the nion Laboratory, Wellington, but partial analyses of both waters have since been made by the writer indicating that the conposition has shown no appreciable change. The most interesting fact is the presence of boron in Hanmer water. The Hanmer water is in regular use for curative purposes and some use is also made of the Maruia spring water.

Hanmer Water	p.p.m.
Metasilicic acid H_2SiO_3	58
Metaboric acid, HBO_2 (equivalent to B_2O_3)	200
Aluminium ion (Al^{+++})	1.0
Calcium ion (Ca^{++})	10.0
Magnesium ion (Mg^{++})	0.3
Sodium ion (Na^{+})	379
Potassium ion (K^{+})	4.0
Ammonium ion (NH_4^{+})	3.0
Sulphate ion (SO_4^{--})	18.9
Chloride ion (Cl^{-})	483
Hydrosulphide ion (HS^{-})	4.7
Bicarbonate ion (HCO_3^{-}) by difference	196
Hydrogen-ion concentration, pH	8.0
Total dissolved solids at 110°C.	1,185

Maruia Springs	
Silica (SiO_2)	71.8
Aluminium ion (Al^{+++})	1.8
Ferric ion (Fe^{+++})	0.2
Magnesium ion (Mg^{++})	0.7
Calcium ion (Ca^{++})	5.7
Sodium ion (Na^{+})	165
Potassium ion (K^{+})	7.9
Ammonium ion (NH_4^{+})	3.6
Sulphate ion (SO_4^{--})	50.7
Chloride ion (Cl^{-})	152
Bicarbonate ion (HCO_3^{-}	139
Iodine (I)	f. trace
Boron trioxide, (B_2O_3)	trace only
Sulphuretted hydrogen, (H_2S)	strong
Total dissolved mineral solids	598

The Lyttelton Harbour group include a series from Charteris Bay, Church Bay, Heathcote and Okain Bay (Bank's Pensula) the analyses of which are recorded by Maclaurin (4). These waters are of total solid content 1,645, 1,160, 1,125 and 11,290 parts per million respectively, and contain magnesium chloride and sulphate, and sodium chloride. They are all unsuitable for domestic, commercial or medicinal use. These analyses have not been repeated in recent years but the writer has examined recently a water from Diamond Harbour containing 6,215 parts per million of solids with a predominance of sodium chloride and the chlorides and sulphates of magnesium and calcium.

Other waters in this locality are reported from Teddington, Kaituna Valley, and the Little River Road.

Mineral waters have also been reported from Amberley, Lake Sumner, lower Otira Gorge, Fox River and the Franz Joseph Glacier, but these are all of low mineralization.

Within the town area of Timaru which is located on a dolerite plateau a number of bores have been sunk and water supplies obtained. One of these recently examined contained 1,240 parts per million of solids with a predominance of chlorides and nitrates. the temporary and permanent hardness of this water were 185 and 70 parts per million respectively..

TOWN SUPPLIES

The following is a summary of the total solid content and hardness of the principal public supplies of Canterbury and West Coast districts. It is again emphasized that for commercial purposes, particularly where artesian water is to be used, an analysis should be made of the individual supply as artesian well waters show slight variations in composition according to locality and strata from which they are derived.

The figures under the heading "hardness" are methyl orange alkalinity expressed as parts per million of calcium carbonate.

Permanent hardness as ordinarily understood is absent or present in negligible quantity in the main Christchurch supply and the other supplies mentioned:-

	TOTAL SOLIDS (p.p.m.)	HARDNESS (p.p.m.)
Christchurch (artesian)	70 to 110	40 to 70
Lyttelton	165	95
Kaikoura	80	50
Hanmer	50	25
Rangiora	65	40
Akaroa	60	30
Ashburton	80	50
Temuka	50	35
Geraldine	60	35
Fairlie	50	35
Timaru	45	35
Waimate	60	40
Westport	50	30
Reefton	55	35
Greymouth	125	55
Hokitika (Lake Kanieri)	55	20
Ross	40	20

ACKNOWLEDGMENTS.

The writer acknowledges the work of members of his staff who have been associated at various times with portions of the above investigations, in particular Messrs N. P. Alcorn, C. F. Denmead, M. Hunter, N. E. Hornby and Mrs D. D. Perrin.

REFERENCES

(1) ROGERS M.N. (1927: *Trans N.Z. Inst.*, 57, 893.

(2) DENMEAD C.F. (1947): *N.Z. J. Sci. and Tech.*, 28, (Sec. B), 158-63

(3) FARR C.C. and FLORANCE D.C.H. (1909): *Trans N.Z. Inst.*, 42, 185.

(4) MACLAURIN J.S. (1907): *Ann. Rept. Dom. Lab.*, 42, 32.

GYPSUM AT WHITE ISLAND

BY C.A. FLEMING, NEW ZEALAND GEOLOGICAL SURVEY, DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH.

[*Received for publication, 8th July, 1947*]

Summary

Gypsum is a common product of hydrothermal alteration in the crater of White Island, but none of the deposits there contain sufficient of the mineral either for the manufacture of plaster of Paris or for use as a retarder in Portland cement, so that economic exploitation of the deposits is impossible.

INTRODUCTION.

The difficulty of satisfying the demand for gypsum in the New Zealand building industry led to the investigation of possible gypsum-bearing deposits at White Island during the expedition of the Department of Scientific and Industrial Research in January, 1947. Gypsum has been noted by most geologists who have visited or reported on White Island during the past 75 years (Hochestetter, 1867; Hector, 1871; Cox, 1882; Bartrum, 1926; Grange, 1927, etc.) and at one time White Island Products Co. obtained a product sold as "sulphur-gypsum fertiliser" which appeared to "contain a fair amount of gypsum" (Grange, *op. cit.*)

TOPOGRAPHY AND GENERAL GEOLOGY.

Detailed accounts of the geology of White Island and of the hydrothermal activity in the crater are in preparation, and the following brief outline serves merely to introduce discussion of the gypsum deposits. More detailed accounts of the island are listed in the bibliography.

White Island is an active volcano situated in the Bay of Plenty some 35 miles north-north-east of Whakatane and 60 miles east of Tauranga. The island occupies an area of about a square mile; its coasts are exposed and rocky and there is no permanently sheltered anchorage for shipping. From the coastline the island rises steeply to heights of over 1,000 ft. except on the east where a steep walled crater has been breached by the sea. The crater is about 60 chains long and 20 chains wide; its floor rises irregularly from sea-level in the east to over 200 ft. in the west, beneath the highest points on the surrounding crater rim (1,053 ft.). Active and dormant fumaroles, hot pools and many small vents are distributed over the central and western portions of the crater, and from these active areas a hot stream drains seawards to Crater Bay. The crater floor is partly covered by irregular mounds of altered andesitic agglomerate formed by a disastrous landslip and lahar of 1914. Projecting spurs from the crater walls, rock slides, talus slopes, and remnants of ancient high level crater floor deposits diversify the margins of the crater.

Occurrence and Origin of Gypsum: The origin of gypsum at White Island has been considered by Bartrum (1926, p. 266) who described how the acidic fumes from active fumaroles attack plagioclase feldspars in the andesitic lavas and breccias to produce sulphates of calcium. Gypsum is still being produced by this method, and is also prominent in altered deposits at the sites of extinct or dying fumarolic activity. Probably no part of the island is quite free from the effects of the permeation of acid gases. All the ephemeral rainwater streams on the outer slopes of the volcano carry dissolved salts, and the ground water that emerges as springs between tide marks on the south coast is hot and strongly acid. Hydrothermal alteration of feldspars to gypsum is thus widespread, and gypsum crystals were observed in the field in decomposed breccias, tuff, and ash, not only near the active fumaroles but on other parts of the crater floor, on the crater walls and even on the outer parts slopes of the volcano.

Nevertheless, as is to be expected, the most conspicuously gypsum-bearing deposits are confined to the crater.

In addition to the occurrence of gypsum in ramifying veinlets or as disseminated crystals in altered andesitic debris, in the walls and in the lahar mounds, this mineral is deposited as layers of varying thickness on the floors of the alluviated flats bordering the hot mineral streams. On the floor of one such flood plain, below the hot acid lake occupying the site of Big Donald Blowhole, a crust of impure crystalline gypsum about an inch thick was arranged in polygonal slabs separated by raised welts. Below the surface crust alternating layers of ashy silt and crystalline gypsum were exposed to the depth of a foot, and a representative sample collected from the surface to that depth proved on analysis to contain 43.8 per cent gypsum. The area of this deposit was less than a square chain.

Horizontal lenticles of acicular and platy crystalline gypsum (selenite) arranged normal to the bedding or in roughly radial clusters are not uncommon in the old crater floor deposits in the portions of the crater, seaward of the site of the lake present prior to the 1914 eruption. Such lenticles, examined in the banks of the Crater Bay Stream, reach a maximum thickness of about 5in. (Fig. 1) but thin within a few yards to an inch or less. The crater floor deposits traversed by the Crater Bay Stream underlie and antedate the mounds deposited by the 1914 lahar. The 3 ft. section exposed shows that such beds consist chiefly of rudely stratified altered breccias and sands with minor lenticles of gypsum as described. A sample taken from a 3 ft. section proved to contain 12.2 per cent. gypsum.

Both the gypsum being deposited at present on flats beside hot mineralized springs and that visible in sections through older deposits probably originated in part by the evaporation and cooling of mineralized waters containing calcium sulphate and in part by the capillary up-rise to the surface of waters containing the salt derived from altered rocks at depth.

In a manuscript report by J.H. Goosman on Sulphur Deposits at White Island, dated May, 1933, (now in the possession of Mr. G.R. Buttle, the owner of White Island), referrence is made to a large tonnage of gypsum on the north coast. This deposit was visited by Mr. J. Healy of the New Zealand Geological Survey and Mr. Buttle on the 22nd Febuary, 1947. The sample of white finely granular material collected by them (N. 337) was found to consist of glassy or colloidal silica and contained no gypsum.

To summarize, gypsum is a characteristic and widespread product of hydrothermal activity at White Island, particularly in the crater where altered agglomerate, talus and lahar mounds all contain the mineral to some extent (14.5 to 19.5 per cent.) in addition, contemporary and ancient crater floor deposits contain very small and localized concentrations of gypsum, although their over-all content of the mineral probably nowhere exceeds 20 per cent.

PROSPECTS OF COMMERCIAL EXPLOITATION.

The economic gypsum deposits of the world are, with few exceptions, located in areas of arid or semi-arid climates or in sedimentary rocks formed under such conditions in the past. Most of such deposits originated by efflorescence, by the evaporation of periodically flooded arms of the sea, by deposition at springs by ground water, or by the disintegration and reaccumulation of pre-existing deposits. Such deposits of gypsum are often remarkably pure, and in the United States, for instance (Stone, 1920) it is not customary to beneficiate gypsum ores except for very special purposes (medical plaster of Paris, etc.).

In Australia (Jones, 1925) gypsum occurs as nodules in clays, earthy superficial deposits of gypsite, and aeolian accumulations from the disruption of originally stratified beds.

Japan, like New Zealand, lies in a middle latitude high rainfall area where present conditions are unfavourable for the deposit of gypsum in workable deposits from normal sea-water and ground-water. Nor, in either country, have conditions during past geologic time favoured gypsum accumulation.

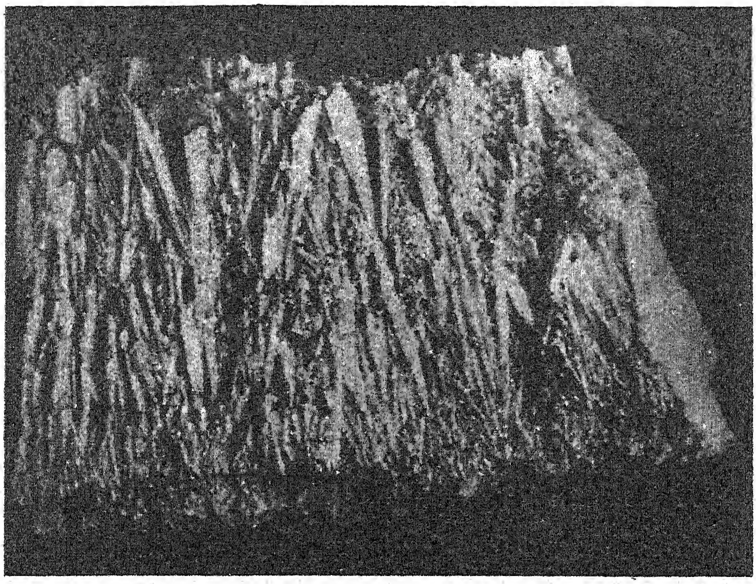


Fig. 1. Portion of lenticle of selenite crystals, from crater-floor deposits exposed in bank of Crater Bay Stream, White Island. The specimen is 8½ inches long and 5 inches thick. Photo by W.H.V. Baker.

In Japan (General Headquarters, Supreme Commander for the Allied Powers 1946) deposits of gypsum are all hydrothermal in orgin, occurring as massive lenticular bodies, usually in tuff, close to igneous intrusions. Japanese gypsum is low in grade, averaging 33 per cent. SO_3 (72 per cent. gypsum) with 0.66 to 3.3 per cent. of the total suitable for plaster manufacture. The Japanese deposits have been adequate to meet the country's demands for cement grade gypsum, but not for plaster grade material, of which 80 per cent. has been imported.

The chief industrial uses of gypsum are (a) calcined, in the manufacture of plaster of Paris and other plasters, and (b) crude as a retarder in Portland cement manufacture.

For the manufacture of plaster of Paris, gypsum ores of a relative purity are necessary, and no such ores have been utilized containing less than 42 per cent. SO_3 (equivalent to 91 per cent. gypsum). None of the White Island deposits approaches such a grade; the richest sample contained 20 per cent. SO_3 (43.8 per cent. gypsum). Unless, therefore, purification of such low grade deposits could be effected economically, there is no prospect of obtaining the raw materials of plaster of Paris at White Island.

In Portland cement manufacture, raw gypsum is used as a retarder, and since the SO_3 is the active retarding agent, the quality of the ore is usually expressed in terms of the percentage of SO_3. In Australia (Jones, 1925, p. 11) it has been noted that "While it is desirable that the SO_3 content of gypsum for use in cement manuf-facture should exceed 40 per cent., lower grade material carrying 35 per cent. can be used with satisfactory results". In Japan (*op. cit.*) gypsum classified as cement grade contains 30-39 per cent. SO_3 (average 33 per cent.). It is unlikely, therefore, that material containing less than 30 per cent. SO_3 could be utilized in cement manufact-

ure. "Gypsum, being bulky for its value, cannot be successfully worked if subject to excessive haulage charges" (Jones, 1925, p. 5) so that any increase in costs incurred by the extraction of gypsum from the impure deposits at White Island (7.2 to 19.5 per cent. gypsum, or 3-9 per cent. SO_3) would almost certainly prevent its utilisation.

CONCLUSION

Althouth gypsum is a common product of the hydrothermal alterations of rocks in the crater of White Island, none of the deposits tested contain gypsum in sufficient concentration even for use as a retarder in cement, and there is no gypsum of sufficient purity for use in plaster manufacture. Any ultization of White Island gypsum would entail refining a low grade ore, a procedure without precedence anywhere in the world. The exploitation of White Island for sulphur and other products at various times within the last 60 years has never been economically successful owing to the cost of maintaining a plant at the island, to shipping and labour difficulties, and, most of all, to the absence of enough suitable ores. The same factors prohibit consideration of the island as a potential source of gypsum for commercial purposes.

TABLE I.- ANALYSES OF GYPSUM-BEARING SEDIMENTS FROM WHITE ISLAND. (DOMINION LABORATORY, J.J.S. CORNES, ANALYST).

DOM. LAB. NO.	FIELD NO.	GYPSUM (PER CENT.)	NATURE OF RESIDUE.
N. 113/1	F 5	14.5	Largely yellowish ferric sulphate.
/2	F 6	43.8	"Clay", with some sulphur.
/3	F 10	19.5	Glassy vesicular andesite; white pieces of partially decomposed rock.
/4	F 11	7.2	Same as 113/3
/5	F 12	18.0	" " "
/7	F 17	12.2	Glassy andesite, but mainly white decomposed rock containing decomposed alkalies.
N. 337	F 18	Nil	All but 3 per cent. glassy or colloidal silica (? residual) with fine pumiceous structure.

LOCALITIES: N. 113/1 (F 5): Foot of crater-wall talus, 8 chains east of Little Donald Blowhole, from cleaned 4 ft. face

N. 113/2 (F 6): One foot cut in surface of alluvial flat near outlet of Green Lake.

N. 113/3 (F 10): Material of 1914 lahar, 5 chains from Crater Bay, from 4 ft. face.

N. 113/4 (F 11): Surface alluvium near fumaroles in Big Donald Area.

N. 113/5 (F 12): Material of 1914 lahar, cleaned 3 ft. face, mound east of Green Lake.

N. 113/7 (F 7): Mouth of hot stream draining into Crater Bay. Cleaned 3 ft. face in old crater floor deposits, exposing gypsum layers up to 3in. thick in sands and fine breccia.

N. 337 (F 18): North slope of White Island, half-way between rim and coast. Deposits of conspicuous white material previously reported as gypsum.

REFERENCES

1. BARTRUM, J.A. (1926): White Island Volcano. *N.Z. J. Sci. and Tech.*, *8*, 261-6.

2. COX, S.H. (1882): Notes on the Mineralogy of New Zealand. *Trans. N.Z. Inst., 15*, 383.

3. GRANGE, L.I. (1927): White Island. *N.Z. Geol. Surv., 21st Ann. Rept.* (n.s.), 19-20.

4. HECTOR, J. (1871): Notes on the Geology of White Island. *Trans. N.Z. Inst., 3*.

5. HOCKSTETTER, F. von. (1867): "New Zealand".

6. JONES, L.J. (1925): The Gypsum Deposits of New South Wales. *N.S.W. Geol. Surv. and Mineral Resources, 33*, 1-45.

7. STONE, R.W. (1920): Gypsum Deposits of the United States. *U.S. Geol. Survey Bull. 697*.

8. General Headquarters, Supreme Commander for Allied Powers (1946): Limestone, Lime and Gypsum Resources in Japan. *Natural Resources Sect. Rep. 60*.

EARTHQUAKES IN NEW ZEALAND, DURING THE YEAR 1946

BY R.C. HAYES, DOMINION OBSERVATORY. DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH, WELLINGTON

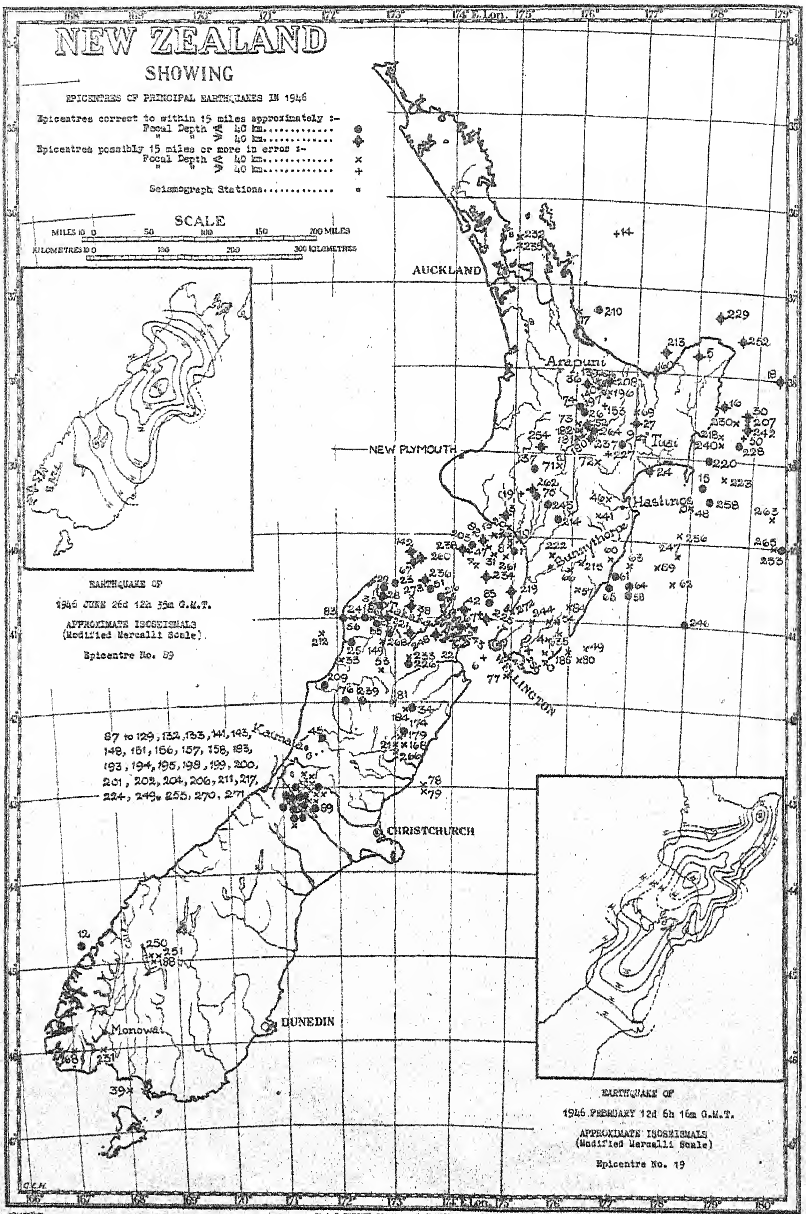
[*Received for publication, 25th July, 1947*]

The accompanying map shows the epicentres of earthquakes in the New Zealand Region during the Year 1946. Shocks with origins deeper than normal are indicated by special symbols. Accuracy of epicentre determination is also indicated.

The two inset maps show the approximate isoseismals of two of the most notable shocks during the year.

Some additional particulars of the earthquakes whose epic- centres are shown on the map, are given below :-

No.	Date and Time (G.M.T.)*	Maximum Felt Intensity (M - M)	No.	Date and Time (G.M.T.)*	Maximum Felt Intensity (M - M)
	1946 d. h. m.			1946 d. h. m.	
1	Jan. 1 13 24.9	II+	44	Apr. 3 10 01.7	V
2	5 22 10ca	II	45	7 21 49.2	-
3	6 02 01.5	IV	46	8 13 06.4	-
4	10 16 40.0	II?	47	8 14 10.7	III
5	14 02 29.2	-	48	9 07 46.5	IV
6	14 07 32.6	III	49	13 10 56.0	III
7	15 10 52ca	I	50	16 21 17.9	V
8	15 12 42ca	II	51	19 19 33.5	-
9	15 14 26.1	-	52	22 18 19.6	III
10	28 11 59ca	III	53	24 02 44.1	-
11	28 16 50.1	IV	54	27 19 54.9	IV
12	Feb. 1 21 38.2	III	55	30 15 33.2	IV
13	2 18 43.3	III	56	May 1 06 44ca	III
14	4 21 47.0	IV	57	2 10 58.4	IV
15	7 00 26.0	-	58	7 07 04.5	IV
16	10 11 12.4	III	59	7 14 13.0	-
17	12 00 40.2	Slight	60	8 01 24.0	II
18	12 05 53.3	-	61	8 03 22.9	II
19	12 06 16.5	VI+	62	8 19 12.6	-
20	15 15 32.7	IV	63	9 00 06.1	-
21	16 03 44.6	III	64	9 04 10.6	IV
22	16 22 53.1	III+	65	9 04 44.6	II?
23	19 09 55.9	III	66	12 10 57.9	II
24	21 07 32.8	IV	67	13 16 35.8	-
25	21 23 46.1	IV	68	17 17 53ca	V
26	24 23 12.6	-	69	19 06 11ca	I
27	26 05 30.8	VI	70	19 18 45.5	- -
28	28 23 37.6	IV	71	22 18 .5.5	-
29	Mar. 1 12 37.4	II	72	23 11 48.2	-
30	4 00 47.0	V	73	25 23 52ca	II
31	4 16 01.9	III	74	June 3 15 30.2	-
32	7 13 50.3	III	75	7 14 15.5	VI
33	8 23 26.8	I	76	9 15 49.3	-
34	9 04 44.9	-	77	10 03 37.5	III
35	9 17 15.8	IV	78	10 18 21.9	III
36	10 06 26.7	-	79	10 18 22.5	IV
37	11 10 35.7	V	80	11 07 30.6	III
38	12 17 04.3	III	81	13 20 02.5	-
39	15 22 56ca	III	82	14 13 05.1	IV
40	17 03 29.0	I	83	15 05 32.2	I
41	24 16 32.9	-	84	16 09 46.4	III
42	25 15 29.2	IV+	85	19 15 42.1	I
43	31 06 10.3	I	86	25 05 02ca	III


NEW ZEALAND
SHOWING
EPICENTRES OF PRINCIPAL EARTHQUAKES IN 1946
Epicentres correct to within 15 miles approximately :-
Focal Depth ≤ 40 km.
" " > 40 km.
Epicentres possibly 15 miles or more in error :-
Focal Depth ≤ 40 km.
" " > 40 km.
Seismograph Stations
SCALE
MILES 10 0 50 100 150 200 MILES
KILOMETRES 10 0 100 200 300 KILOMETRES
EARTHQUAKE OF
1946 JUNE 26d 12h 35m G.M.T.
APPROXIMATE ISOSEISMALS
(Modified Mercalli Scale)
Epicentre No. 89
AUCKLAND
NEW PLYMOUTH
Arapuni
Tuai
Hastings
Bunnythorpe
WELLINGTON
Kaimata
CHRISTCHURCH
DUNEDIN
Monowai
87 to 129, 132, 133, 141, 145, 148, 151, 156, 157, 158, 183, 193, 194, 195, 198, 199, 200, 201, 202, 204, 206, 211, 217, 224, 249, 255, 270, 271
EARTHQUAKE OF
1946 FEBRUARY 12d 6h 16m G.M.T.
APPROXIMATE ISOSEISMALS
(Modified Mercalli Scale)
Epicentre No. 19
W. A. G. SKINNER, GOVERNMENT PRINTER, WELLINGTON.

No.	Date and Time (G.M.T.)*		Maximum Felt Intensity (M - M)
	1946	d. h. m.	
87	June	26 12 13.3	II
88		26 12 33ca	III
89		26 12 34.7	VII+
90		26 12 53.9	III
91		26 13 06.7	III
92		26 13 16.9	III
93		26 13 17.7	III
94		26 13 29.9	III
95		26 13 41.3	III
96		26 14 15.8	III
97		26 14 45.3	IV
98		26 15 42.5	-
99		26 16 30.5	-
100		26 22 18.5	III?
101		27 02 00.3	-
102		27 03 07.4	-
103		27 04 05.2	-
104		27 04 08.1	-
105		27 08 20.0	IV
106		27 18 36.1	III
107		28 00 35.4	IV
108		28 06 28.5	III
109		28 06 34ca	II
110		28 06 50ca	III
111		28 06 58.9	IV
112		28 07 04.4	III
113		28 07 12.8	VI
114		28 07 15.2	III
115		28 07 22.6	III
116		28 07 59.1	IV
117		28 08 52.6	V
118		28 09 03.7	III
119		28 18 56.7	III
120		29 19 46ca	I
121		29 19 48.1	II
122		30 08 03ca	II
123		30 08 21ca	I
124		30 08 32ca	III
125		30 08 38ca	III
126		30 08 49ca	III
127		30 21 04.5	—
128		30 21 07.6	V
129	July	1 06 54.4	III
132		1 15 37.0	III
133		2 08 27.2	IV
139		3 18 15ca	III
140		3 19 15ca	I?
141		4 10 16.8	IV
142		4 18 00.0	III
143		4 18 01.0	III
148		6 08 29.4	II
149		6 18 20.4	III
151		7 07 55.4	III
153		8 14 36.3	IV
156		9 01 53.0	II
157		9 07 55.3	IV
158		9 10 12.9	II
160		10 05 12.9	-
168		12 23 05.5	-
174		16 22 41.8	II
179		22 15 59.9	IV

No.	Date and Time (G.M.T.)*		Maximum Felt Intensity (M - M)
	1946	d. h. m.	
180	July	23 02 09ca	I
181		23 02 11ca	I
182		23 02 30ca	I
183		24 05 09.5	II
184		24 09 04.1	IV
185		25 16 44.9	III
188		28 17 15ca	III?
193		31 10 12.6	III
194		31 10 17.3	I
195	Aug.	1 17 19ca	IV
196		2 18 15ca	III
197		5 16 45ca	III?
198		7 00 01.7	II
199		8 07 26ca	II
200		9 01 37.1	III
201		9 20 09ca	II
202		10 21 18ca	II
203		12 05 08.8	IV
204		12 10 01ca	III
205		12 13 41.4	-
206		12 18 54.5	IV
207		14 05 23.8	I
208		14 15 53.3	-
209		16 12 38.5	III
210		17 04 39.3	III
211		17 07 29ca	II
212		17 15 27.7	II
213		18 17 40.4	-
214		21 21 38.4	IV
215		24 08 42.6	III
216		25 20 24.8	-
217		26 04 28.7	III
218	Sept.	2 13 06.8	II
219		6 11 48.6	III
220		7 05 03.2	-
221		12 13 31.7	-
222		12 14 32.1	III
223		14 10 51.5	VI
224		15 20 25ca	IV
225		16 10 04.9	III
226		18 07 20.9	-
227		22 00 26.8	-
228		22 16 59.8	III
229		24 06 40.7	III
230		24 07 42ca	III
231		26 19 28.8	III
232	Oct.	2 06 45ca	?
233		6 20 40ca	III?
234		8 01 57.0	
235		9 04 34.2	II
236		10 04 00.1	-
237		11 04 07.3	-
238		12 19 55.5	-
239		14 08 05.9	?
240		14 16 51.0	III
241		15 02 39.6	III
242		15 22 11.4	-
243		16 20 40.7	III
244		20 15 15.6	III
245		21 05 00.9	IV
246		23 13 49.3	-

No.	Date and Time (G.M.T.)*				Maximum Felt Intensity (M -M)
		d.	h.	m.	
	Oct.				
247		26	03	29.1	?
248		26	23	14.4	IV
249	Nov.	4	16	54.0	IV
250		4	22	07ca	III
251		5	00	36ca	II
252		8	06	25.4	II
253		11	22	53.8	-
254		13	00	59.5	-
255		15	01	47ca	III
256		21	16	09.8	IV
257		25	11	49.1	-
258		29	15	53.8	-
259	Dec.	2	08	26.1	IV
260		9	17	45.3	IV
261		12	10	55.7	II
262		12	14	39.9	IV
263		12	23	45.5	-
264		14	22	17.0	-
265		16	19	32.0	-
266		17	05	05.2	IV
267		19	15	11.5	II
268		20	06	40.2	III
269		25	03	11.7	III
270		25	-	-	IV
271		28	-	-	IV
272		28	05	15ca	III
273		28	15	32.5	III

* G.M.T.(Greenwich Mean Time) is 12h 00m slow on New Zealand Standard Time. The epicentres on Nos. 70 and 205 are outside the boundary of the map.

The following small shocks in the Lake Coleridge region are not tabulated:-

Nos: 130, 134, 135, 138, 144, 145, 146, 147, 150, 152, 154, 155, 159, 161, 162, 163, 164, 165, 166, 167, 169, 170, 171, 172, 173, 176, 177, 178, 186, 187, 189, 190, 191, and 192.

THE ODOUR OF *COPROSMA FOETIDISSIMA*.

BY MAURICE D. SUTHERLAND, AUCKLAND BRANCH, DOMINION LABORATORY.
DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH.
[*Received for publication, 3rd April, 1947*]

Summary

Methyl mercaptan has been isolated from *Coprosma foetidissima*, and is probably the principal substance causing the foul odour of the plant.

INTRODUCTION

The foul odour of the shrub, *Coprosma foetidissima* Forst., has been remarked on by Laing and Blackwell (1) in their manual, "Plants of New Zealand", in the following terms:- "The name (Coprosma) is derived from the Greek, and refers to the evil odour that the leaves of certain species give out when bruised. Anyone who has forced his way through scrub, formed of the well named *C. foetidissima*, knows that the smell from it becomes in time almost insufferable. The stench is somewhat suggestive of carbon bisulphide, but apparently no attempt has yet been made to determine its source". Cheeseman (2), who notes that it has a "horribly disagreeable" odour, states that it is found from the Thames goldfield and Raglan southward, from sea level to 4,500 ft.

To determine the nature of the odour, the plant was steam distilled, and in the distillate was identified methyl mercaptan and a trace of an essential oil.

As little as 2×10^{-12} g. of ethyl mercaptan can be detected by the nose (3), and it is probable that quantities of methyl mercaptan of the same order are similarly detectable. Consequently only minute quantities of methyl mercaptan need be present in the leaves of the plant, and in the air of the beech forests, to give characteristic odour.

Indeed, since the boiling point of methyl mercaptan is below normal air temperatures, very little mercaptan could be retained by the leaves unless in combination.

The odour of the plant is quoted above as "somewhat suggestive of carbon bisulphide" but a possibility of confusion arises from the fact that pure carbon bisulphide has a weak, sweet smell similar to that of carbon tetrachloride, whereas the crude material often has a strong and foul odour probably due to the presence of small quantities of mercaptans.

Methyl mercaptan has been obtained from two other genera, one of the *Cruciferae* and one of the *Rubiaceae* family. Ground roots of *Raphanus sativus* were shown by Nakamura (4) to yield this substance on steam distillation. From the leaves of a number of species of the genus *Lasianthus* which have been described as smelling strongly of skatole, Koolhass (5) obtained methyl mercaptan both by steam distillation and by aeration. It is thus probable that many of the foul smelling plants of the *Rubiaceae* family, and *C. foetidissima* in particular, owe their odour to methyl mercaptan.

EXPERIMENTAL

A weight of leaves estimated to be 5 lb. was gathered in the beech forests of Tongariro National Park, placed immediately in a four gallon can with ample water, and distilled until the foul smelling distillate no longer gave a positive test for mercaptan when treated with mercuric chloride solution. The distillate was sealed in bottles filled to the cork, and later examined in Auckland Colour tests for mercaptans were positive. A sample of distillate was slowly heated to boiling as a stream of purified hydrogen gas was passed through it and then through a strongly cooled solution

of mercuric cyanide in methyl alcohol A white precipitate formed and was filtered off and dried. Placed in a melting point apparatus at 170°C. this substance melted with decomposition at 173°C. It was recrystallized from ethyl acetate and then melted at 175°C. both alone, and when mixed with mercury dimethyl mercaptide m.p. 175°C. prepared from synthetic methyl mercaptan (6). Thus the presence of methyl mercaptan (by iodometric titration 0.005 per cent. of the estimated weight of leaves) in the distillate was proved. The methyl mercaptan contained in the distillate was, however, only a portion of that evolved by the leaves since much escaped as a gas.

REFERENCES

(1) LAING and BLACKWELL (1940): "Plants of New Zealand" p. 147.
(2) CHEESEMAN (1925): "Manual of New Zealand Flora" Wellington.
(3) FISCHER and PENZOLDT (1887): *Annalen, 239,* 131
(4) NAKAMURA (1925): *Biochem. Ztschr., 164,* 31.
(5) KOOLHAAS (1931): *Biochem. Ztschr., 230,* 446.
(6) BLACKBURN and CHALLENGER (1938): *J. Chem. Soc.*, 1872.

A NOTE ON TECTONIC AND STRUCTURAL LANDFORMS.

BY C.A. COTTON, VICTORIA UNIVERSITY COLLEGE, WELLINGTON.

[*Received for publication, 15th July, 1947*]

According to English usage now well established, the word "tectonics" may be written when "folded and faulted structure" is meant.[1] The adjective "tectonic," however, as defined by Holmes,[2] is not the exact equivalent of "structural", but "refers to any structural change brought about by deformation or displacement of rocks," i.e. to the change, not the structure itself, which is a static conception. The application of "tectonic" to the classification and description of earthquakes is an example of correct usage.

By New Zealand geologists "structural" is commonly employed with reference to the origin of major forms of relief in cases where "tectonic" could be written with less ambiguity. Tectonic forms owe their origin to earth movements, and in the description and explanation of landscape forms it is important to distinguish between tectonic and erosional relief, if the former is present. A tectonic landform, moreover, is not the same thing as a structural landform, for, according to long established usage, the latter description is applied to one that has been developed by erosion under the control of structure.

1. See, for example, L.W. COLLET, "The Structure of the Alps," London, 1927, *passim*.

2. A. HOLMES, "The Principles of Structural Geology," London, 1944, p.358.

STUDIES ON PERLOLINE III.

BY W.S. METCALF, VICTORIA UNIVERSITY COLLEGE, WELLINGTON.
[*Received for publication, 15th August, 1947*]

Summary.

In an earlier paper (2) of this series it was suggested that perloline (1) formed a dihydrochloride of formula $C_{40}H_{34}N_4O_7(HCl)_2$. The experiments described in this paper show that perloline forms only a monohydrochloride, whose formula, to be consistent with the analytical data (3), must be close to $C_{20}H_{18}N_2O_4(HCl)$, or perhaps $(C_{20}H_{18}N_2O_3)_2(HCl)_2H_2O$. By analogy it seems likely that the formulae of all the derivatives of perloline, including perlolidine (4) should also be halved.

White (5) was unable to prepare a "monohydrochloride" by crystallizing an equimolar mixture of the free base and the "dihydrochloride".

The absorption spectrum of perloline (6) in aqueous buffers throughout the range pH 0-14 can be completely accounted for by only two optically distinguishable forms. One, the free base which can be readily extracted by chloroform, exists in the pH range 9-14, while the other, presumably the singly charged ion, exists in the pH range 0-8. Both forms exist together in equilibrium near pH 8.5. Any further change in ionic charge would almost certainly be accompanied by a marked change in spectrum, because the highly unsaturated nature of perloline and the chemical evidence (2) make it highly probable that all the nitrogen atoms are in the absorbing part of the molecule (7). No such spectral change is found, even in strongly acid solutions.

The possibility remains that the ion is doubly charged, losing both protons at once to form the free base. This seems without parallel among organic bases. That it is not the case with perloline is shown by the following measurements of the equilibrium constants of the reactions

$$B + H^+ \rightleftharpoons BH^+$$
$$B + 2H^+ \rightleftharpoons BH_2^+$$

The fraction of alkaloid present as the intense yellow free base B in a buffered solution can be determined by matching the solution in a dip type colorimeter against a solution of the alkaloid in dilute alkali, in which it is all in the form of free base, both solutions containing the same total weight of alkaloid (5 micrograms in 5 ml.). Allowance is made for the very slight yellow colour of the ionic form. From this fraction the ratio of the concentrations of free base and ion is calculated and substituted in the equilibrium equations

$$K' \rightleftharpoons \frac{[B]\ [H^+]}{[BH^+]} \quad \text{and } K'' \rightleftharpoons \frac{[B]\ [H^+]^2}{[BH_2^{++}]}$$

K and K" were calculated for a number of values of the pH, activity coefficients being taken as unity.

pH	7.62	8.14	8.29	8.51	8.68	8.80	8.91	9.01	9.09
pK'	8.65	8.45	8.46	8.55	8.61	8.57	8.47	8.58	8.52
pK"	16.27	16.59	16.76	17.06	17.29	17.37	17.38	17.59	17.61
S.E.M. of six matchings	.04	.03	.02	.02	.02	.02	.04	.04	.06

The values of pK' are satisfactorily constant but the values of pK" steadily increase as the pH rises. We conclude that one

hydrogen ion is involved in salt formation - not two as has been assumed.

The buffers (8) were mixtures of M/20 borax and M/10 hydrochloric acid. The temperature was 18 ± 3°C.

Under these conditions

$$pK = 8.54 \pm .03.$$

A further uncertainty of about 0.1 is introduced by the assumption of activity coefficients of unity, and the difficulty of standardizing the pH scale in the alkaline region.

The change in absorption spectrum on ionisation suggests that the basic nitrogen atom is either in an aromatic ring system or attached thereto directly or by conjugation. The strength of the base is much greater than that usually found among such compounds. It is much nearer the basic strength of ammonia and aliphatic amines. Any proposed structure must account for this unusual behaviour.

The author is indebted to Mr. E.P. White for a pure sample of perloline and for discussion.

REFERENCES

(1) GRIMMETT, R.E.R. and MELVILLE, J. (1942): *N.Z. J.Sci. and Tech.*, *24*, 149B.

(2) WHITE, E.P. and REIFER, I. (1945): Ibid, *27* (*Sec. B*), 38.

(3) REIFER, I., and BATHURST, N.O. (1943): Ibid, *24*, 155*B*.

(4) WHITE, E.P. and REIFER, I. (1945): Ibid, *27*, (*Sec. B*), 242.

(5) Private communication.

(6) To be published later.

(7) BRODE, W.R. (1943): "Chemical Spectroscopy". John Wiley, New York, p.213.

(8) SORENSEN, (1912): *Ergeb. Physiol.*, *12*, 393, quoted by BRITTON H.T.S. (1929): "Hydrogen Ions". Chapman, London.

THE NEW ZEALAND

JOURNAL OF SCIENCE AND TECHNOLOGY

Editor: D. Cairns, M.Sc. (Assistant Editor: M. O'Connor, M.Sc.) Department of Scientific and Industrial Research, Wellington

VOL. 29. SEC. B NOV., 1947 NUMBER 3

SERPENTINITE AT WAIRERE, TOTORO SURVEY DISTRICT, KING COUNTRY

By C. A. FLEMING, New Zealand Geological Survey, Department of Scientific and Industrial Research

(*Received for publication, 16th July, 1947*)

Summary

A deposit of serpentinite on Rangikohua Road, Totoro S.D., has been mapped and prospected and the quantity of serpentinite available for quarrying assessed. Analyses (by the Dominion Analyst) and petrological descriptions (by Dr. C. O. Hutton) are included. The relations between the serpentinite and other rocks (Mesozoic and Tertiary sediments) are discussed as a basis for deductions concerning the age of the igneous rock and its structure and history. It is suggested that a late Eocene peridotite intrusion into steeply dipping Mesozoic sediments has later been thrust by diapiric folding into overlying sediments of Oligocene and Miocene age.

INTRODUCTION

IN *New Zealand Geological Survey Bulletin No. 24*, "The Geology of the Mokau Subdivision," (Henderson and Ongley, 1923) serpentinite was reported on the Rangikohua Road, Totoro S.D. In *Bulletin No. 41*, "The Geology of the Te Kuiti Subdivision" (1946) petrological descriptions of two serpentinites from Rangikohua were presented and the serpentinite body mapped in relation to other formations.

In March, 1944, when the need was pressing for further sources of serpentinite for the fertilizer industry, to supplement the amounts obtained from North Auckland, preliminary magnetic investigation and mapping of outcrops by the writer indicated a substantial mass of serpentinite and other igneous rock at Wairere. In August, 1944, arrangements were made for the Works Department, Taumarunui, to prepare a contour plan of the deposit, and to prospect by pitting and trenching. This work was completed in the spring of 1944, and in January, 1945, the writer (with the assistance of Mr. A. C. Beck, New Zealand Geological Survey) inspected and mapped the excavations and traced the serpentinite to its limits to the north.

GENERAL DESCRIPTION

The Wairere serpentinite is an irregular linear mass extending some 27 chains in a direction 10° east of north, and 5 chains south, of its outcrop on Kohua Road, a total distance of 32 chains. Its breadth varies appreciably; it is widest ($2\frac{1}{2}$ chains) at Kohua Road, but narrows abruptly to the south. North of the road, the breadth of the body varies owing

to the sinuosity of its eastern contact, a relatively low-angle thrust plane, which results in the serpentinite being narrower where ridges of sandstone buttress on to it, but wider in country of lower relief between such side-spurs. Eventually, 27 chains north of the road, the outcrop thins to a narrow point (Figs. 1 and 2).

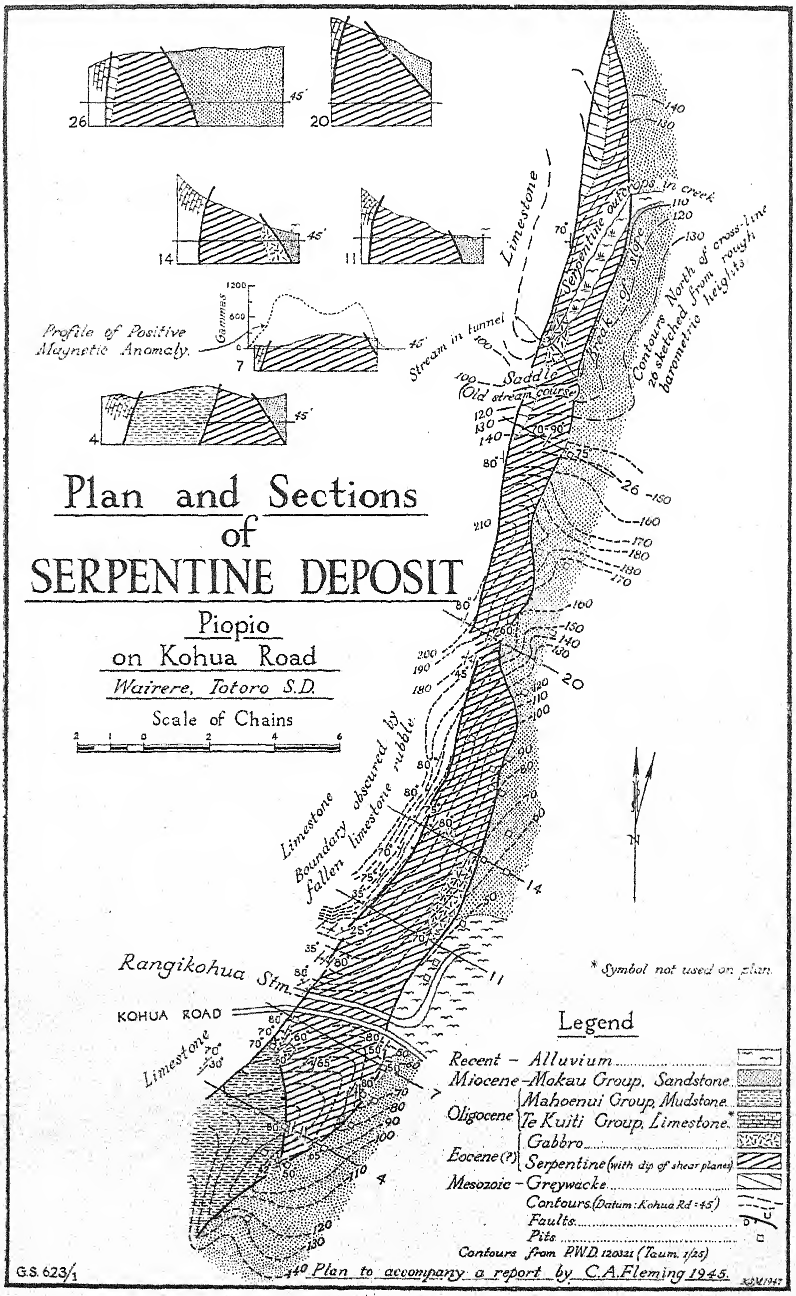


FIG. 1.

South of Kohua Road, the expanded southern end of the deposit forms a rounded spur rising steeply from Rangikohua Stream. North of the stream a ridge of sub-vertical Te Kuiti limestone forms the crest, and serpentinite forms the east slope of a meridional ridge. The ridge is joined by spurs of siltstone and sandstone belonging to the Mokau formation, which lap on to the serpentinite, narrowing its surface outcrop at a number of points. Twelve chains north of the road, the serpentinite has climbed to the top of the ridge and the limestone is down the west flank. Twenty chains north of the road a west-flowing tributary of the Rangikohua has at one time carved a valley across the ridge of serpentinite and limestone, but now flows underground in a tunnel within the limestone which it enters at the contact between limestone and serpentinite. North of the cross valley, the ridge maintains its character for about 3½ chains, with subvertical limestone to the west of the serpentinite and Mokau sandstones to the east, but further to the north the Mokau sediments gradually encroach upon the serpentinite body, the limestone ceases to outcrop, and a wedge of greywacke forms the west slope of the ridge. North of the divide, near Warren's south boundary, the serpentinite and greywacke are cut out by the approach of Mokau sandstone to the Te Kuiti limestone and further north the limestone is faulted against Mokau beds without intervening serpentinite.

Associated with the serpentinite body are small lenses of gabbro and wedges of greywacke sediment of relatively small size, so far as can be judged from surface appearances.

PROSPECTING

Magnetic Survey:

The preliminary magnetic work was limited to the area within 80 yd. on either side of the Kohua Road and has not so far been extended to cover the whole area of outcropping serpentinite. Magnetic anomalies connected with the serpentinite and associated rocks consist of a " high " in which there are possibly two ridge-like magnetic " peaks " parallel to the elongation of the body; and, to the east of the body, a " low " of moderate intensity. Positive anomalies exceeded 1000 gammas in several places, the maximum positive reading being 1157 gammas* and the total range of variation 1330 gammas. The total range of magnetic variation compares more closely with the range over the small North Auckland serpentinites than with that found by Jones (1939) for Nelson serpentinites; but, on the other hand, high positive anomalies are usually limited to closely defined " magnetic peaks " in North Auckland.

The distribution of positive anomaly in the limited area where magnetic observations were made corresponds in general with the geological boundaries between serpentinite and Tertiary rocks (Fig. 1, Section 7.) so indicating that serpentinite is limited to the axis along which it outcrops and is not present at depth any great distance east and west of its surface outcrop†. On the other hand, positive anomalies of high order persist along the axis south of the outcropping rock, in an

* Consistent readings on Tertiary rocks on either side of the serpentinite were arbitrarily taken as normal magnetic values for the area.

† This statement is subject to the reservation that no regional work has been undertaken for the assessment of " normal " in the district.

area mapped as claystones of the Mahoenui Group, and this is interpreted as evidence of the presence of serpentinite at depth below the sediments. The western boundary of the area of positive anomaly swings on to limestone near the crest of the ridge two or three chains north of the road: where the limestone is in vertical contact with serpentinite, in the valley, the magnetic and geological boundaries correspond: but where the limestone dips west at the top of the ridge the magnetic boundary encroaches on the limestone suggesting that the serpentinite surface plunges west beneath this west-dipping limestone. Similarly, positive anomalies occur on the alluvium 50 links east of the serpentinite outcrop and indicate that the embayed contact with alluvium for 3 chains north of the road is due to erosion of the serpentinite by the Rangikohua Stream.

A complete magnetic survey of the whole body and of the area east of Ratima's Quarry in the Mokauiti Valley where serpentinite is reported to occur would furnish important information for the interpretation of structural relations (see Fig. 2).

Geological Prospecting:

Trenches and pits dug across the serpentinite body and at contacts enabled the surface expression of the structure to be mapped and permitted examination of shear planes within the serpentinite, and of contact relationships.

The west side of the serpentinite is in contact with steeply dipping or vertical limestone. The east boundary is defined by sandstones and siltstones in which bedding planes are seldom clear adjacent to the igneous rock but which dip east, that is away from the serpentinite, at a nearby outcrop, and which are relatively flat in a road cutting 20 chains to the east. Where the contact was examined, the surface of the serpentinite was observed to plunge beneath siltstones to the east at 50° to 65°, the strike of such plunging surfaces being parallel to the general strike of the body, as mapped. Further, the relation between the sinuosities of the eastern boundary and the topographic irregularity is such that when the heights of adjacent contacts are projected along the strike of the body on to a cross profile, they fall on a line dipping at 45° to 65° eastward. For these reasons the eastern boundary is interpreted as a relatively low angle thrust plane dipping eastward at about 50°.

To the south, the serpentinite boundary swings abruptly away from the steeply dipping limestone which elsewhere defines the western contact and the serpentinite plunges at a high angle beneath claystones here attributed to the Mahoenui formation (Fig. 2).

The outcrop of the igneous body consists for the most part of dunite and harzburgite (bastite) serpentinite, the latter invariably consisting of ovoid or lensoid *augen* up to several feet in diameter, flattened and oriented parallel to the dominant shear planes, set in a much sheared matrix of enwrapping dunite serpentinite. Where dunite serpentinite is alone present several shear directions are usually visible. The dominant shear planes strike in approximately the direction of elongation of the body, and the dominant plane is in many places parallel to the nearest contact with the surrounding sedimentary rocks, dipping at a high angle.

Feldspathic rocks were encountered at four separate points. They consist of coarse-grained gabbro and invariably occur as residual surface boulders with a maximum size of a cubic yard, interpreted as "*augen*" eroded from the serpentinite body to which they had a relation

similar to that of the bastite serpentinite mentioned above. A petrological description of one such rock is appended. The occurrence of gabbro residuals in large numbers within small areas points to localized lenses or patches in which gabbro dominates in the underlying rock body.

Mesozoic greywacke and argillite outcrop in two small areas on the western border of the serpentinite. They are interpreted as having been dragged up with the serpentinite in the diastrophic movements which brought the serpentinite into contact with the younger sediments that surround it.

An estimation of quantities of serpentinite has been made from cross sections drawn up from the available information, and is based on a number of inferences drawn from the geological intrepretation of the prospecting data.

The western contact is believed to be practically vertical at depth even when it is west dipping at greater altitudes, and the eastern contact is inferred to dip east at about 50°. These relations are believed to hold at least down to the level of Rangikohua Stream which was the datum level above which quantities are assessed. The small areas of greywacke and of gabbro mapped on the surface are considered, for the purpose of estimating quantities, to be columns of uniform section area down to the datum level.

Quantity of Serpentinite :

Quantities of serpentinite have been worked out by allowing that 1 cu. yd. of serpentinite weighs 1.8 tons.

All quantities have been assessed down to the 45 ft. level on the Public Works Department plan, the level of Rangikohua Stream where it crosses the serpentinite. Lowering of quarry floors locally below that level may be possible, but would be limited by the flooding tendencies of the stream. In the higher country to the north, quarrying to the 45 ft. level would entail excavations over 150 ft. in depth, and such deep quarries might not be feasible. Also, such deep quarrying would entail shifting of large quantities of overburden from the eastern hanging wall of the deposit.

Quantities are presented under three headings : (A) South of Kohua Road where prospecting has been most exhaustive, and where the situation is favourable for immediate quarrying with little development.* (B) From Rangikohua Stream north to the limit of the Public Works Department prospecting at cross section 26. This area requires bridge access, contains a lens of gabbro, and has, in parts, a variable overburden of limestone rubble. (C) From section 26 north to the end of the deposit. No contour survey is available for this area, which lies over a quarter-of-a-mile from the road, and contains wedges and splinters of greywacke and gabbro, so is likely to be the last part quarried. Quantities for area C are less accurate than those for A and B.

Area A. South of Kohua Road :

Quantity down to 45 ft. contour : 99,000 tons.
(For every 10 ft. of lowering of floor below the 45 ft. level, 25,000 tons).

---

* Quarrying began late in 1945, and 14,307 tons of serpentinite had been recovered by 31st March, 1947, at rates of up to 450 tons per week, the rate of extraction depending upon the availability of railway trucks. The serpentinite is conveyed by motor lorry to the railway at Te Kuiti, a distance of some 21 miles.

Area B. Rangikohua Stream to Cross Section 26 :

Quantity down to the 45 ft. contour : 840,000 tons.

Area C. Cross Section 26 to Northern Limit :

Approximate quantity down to 45 ft. contour : 280,000 tons.
Total serpentinite above level of Rangikohua Stream : 1,219,000 tons.

Overburden :

Overburden is light over the top of the serpentinite, but full exploitation of the deposit would require the shifting of increasing amounts of sedimentary rock, especially along the eastern hanging wall of the deposit. Therefore, the amount of overburden may be presented under two headings, for each area : the amount covering the serpentinite at the surface, which would be unavoidable overburden in working the deposit, and the amount which would need removal for full exploitation of the deposit down to the 45 ft. base. The latter figure is an approximation only.

	Initial overburden.	Additional overburden for full exploitation.
Area A :	2,760 cubic yards	8,250 cubic yards
Area B :	12,280 ,, ,,	82,200 ,, ,,
Area C :	Approx. 5,000 cubic yards	Approx. 33,000 cubic yards

Quality of Serpentinite :

The Wairere serpentinite body is composed chiefly of dunite serpentinite interspersed with boulders, or "augen", of harder bastite serpentinite which represent harzburgitic variations in the original peridotite intrusion. Both the above rocks are satisfactory serpentinite for use in serpentine-super-phosphate fertiliser. A complete analysis by the Dominion Analyst (quoted from Henderson and Ongley, 1923, p. 55) is as follows :—

SiO_2	36.03
Al_2O_3	4.66
FeO	1.58
Fe_2O_3	5.92
CaO	0.20
MgO	36.17
Na_2O	0.06
K_2O	0.04
H_2O (combined)	13.88
H_2O (at 100°c.)	1.55
	100.09

The following six partial analyses for soluble MgO and R_2O_3 are of samples collected south of Kohua Road.

	Soluble MgO	R_2O_3
1	35.8	7.08
2	32.6	9.1
3	27.1	17.8
4	33.3	9.3
5	34.8	8.7
6	35.5	8.5

Nine samples from between Kohua Road and cross section 26 of the Public Works Department survey have been examined petrologically by Dr. C. O. Hutton, New Zealand Geological Survey,* and pronounced to be satisfactory serpentinite.

Factors Affecting Quarrying Operations:

The limestone bounding the serpentinite to the west is capable of forming an almost vertical wall when quarried. The Mokau sandstone to the east is fairly competent where eroded into bluffs elsewhere in the district, and should present no great difficulty. The Mahoenui beds, bounding one side of the serpentinite to the south are, however, of incompetent greasy claystones and mudstones, similar in lithology to the Onerahi claystones which have given such trouble in North Auckland serpentinite quarries. They are unlikely to stand exposure in a vertical face, and will slip freely.

The small stream flowing north along the east boundary of the deposit south of the road will require to be diverted, piped, or pumped when the deposit is opened. Rangikohua Stream tends to flood, but seldom covers Kohua Road.

The small amounts of gabbro and greywacke mapped within the boundaries of the deposit are likely to be encountered sooner or later in quarrying and their by-passing, or removal, will present particular problems. It is of course impossible to predict the subsurface distribution of these rocks without detailed drilling information.

Quantities presented above, it should be noted, are total quantities in the deposit, and not an estimation of quarryable quantities.

PETROLOGY

Dr. C. O. Hutton has supplied the following descriptions of rocks from the Wairere serpentinite body. The first two are quoted from *N.Z. Geological Survey Bulletin No. 41*, p. 59.

"Two specimens of serpentinites from the disused road-metal quarry on the south side of Rangikohua Road have been examined. These rocks are composed essentially of serpentine minerals, P. 1 having been derived from a dunite while P. 2, with plentiful clear bastite, has been originally a harzburgite :—

"*No. P. 1: Dunite-serpentinite.* In the hand specimen this is a massive olive green rock with a talcose sheared surface. In thin section the rock is seen to be composed of a poorly ferriferous, pale green serpentine with typical mesh-structure. Primary and secondary magnetite and a few micro-veins of chrysotile occur.

"*No. P. 2: Harzburgite-serpentinite.* Macroscopically this specimen is a massive, grey serpentinite with easily recognizable plates of bastite. In thin section typical mesh-serpentine and abundant plates of clear bastite, the latter pseudomorphous after a poorly ferriferous orthorhombic pyroxene, make up the bulk of the rock. Clusters of rounded grains of deep brown chromite, abundant secondary magnetite, in sinuous strings of fine grains and narrow veinlets of colourless chrysotile are present.

"From photographs of the ultrabasic intrusion and from an examination of the hand specimens it is clear that the intrusive mass has suffered from shearing movements, but microscopic investigation gives

* Now Professor of Mineralogy, Stanford University, California

no evidence that this shearing has been very intense. Such evidence would be the occurrence of plentiful talc and the platy mineral antigorite, features which are very characteristic of the highly sheared ultrabasic intrusives of the western Otago region. Instead, the rocks are merely dunite-serpentinite and harzburgite-serpentinite, closely comparable with those of the Kerr Point-North Cape mass* (Bartrum and Turner, 1928) and the few less altered intrusives of western Otago (Hutton, 1936)."

Dr. Hutton has provided the following description of a specimen of gabbro from a residual boulder collected from the largest area of such gabbro augen mapped.

Gabbro with Cataclastic Structures : "The only specimen (P. 9354) belonging to this group has a cataclastic structure so well developed that the mutual relationships between the principal constituents have been almost completely destroyed. The plagioclase, with a very patchy development of twinning on the albite law, is decidedly sodic, ranging in composition from An_{15}-An_{22}. Evidence of considerable stress is instanced by the fractured, granulated, and stretched feldspar plates, in addition to the development of clinozoisite and pumpellyite as inclusions within the oligoclase ; these constituents have developed as a result of the break-down of the original more calcic plagioclase, but the percentage of epidote minerals in the rock itself is too small to account for all of the anorthite molecule, so that in view of its well-known mobility, much of the lime must have migrated to crystallize elsewhere in veins as epidote, pumpellyite or prehnite. The occurrence, in this specimen, of a narrow vein, averaging 2 mm. in width, and composed of prehnite, pumpellyite, together with minor opal is an example of this transference and segregation.

Clinopyroxene is present to the extent of approximately 40-50 per cent., and the crystals considerably ruptured by stress. In some grains lamellar twinning on the orthopinacoid has been developed, and a somewhat unusual feature is the relatively small optic axial angle; values ranging from 33-39° have been determined by universal stage methods. In view of this the pyroxene would appear to lie within the field of subcalcic augite as defined by Benson (1944, pp. 114-5) and just outside the pigeonite field. Narrow reaction rims of green to greenish-brown hornblende were noted in association with the clinopyroxene, and the alteration of both of these constituents to serpentinous products, sometimes bowlingitic, is general.

"Pools, augen, and schlieren of serpentine (possibly associated with some chlorite) are frequent, and whereas in some cases it has clearly developed from both clinopyroxene and amphibole, in other instances the poorly-developed mesh effect suggests derivation from olivine. However, no relict olivine was noted. Rare scraps of red-brown biotite, now mostly chloritized, leucoxenized iron-ore, and slender fractured prismatic crystals of apatite complete the mineral assemblage."

GEOLOGY

General Stratigraphy :

The stratigraphical succession in the part of the Te Kuiti-North Taranaki region adjacent to the Wairere serpentinite mass is as follows

* Also closely comparable with the serpentinites of the small peridotite bodies of the Silverdale district. North Auckland.

(from Marwick, *N.Z. Geological Survey Bulletin No. 41*, 1946, and Grange, *N.Z. Geological Survey Bulletin No. 31*, 1927; age determinations based on Finlay and Marwick, 1947).:—

STAGE	AGE	GROUP*	THICKNESS
? Castlecliffian	Late Pliocene	Ignimbrite	
	Unconformity		
Tongaporutuan	Upper Miocene	Tongaporutu Mohakatino	100-200 ft.
? Waiauan to Clifdenian	Mid Miocene	Mokau	200-600 ,,
	Unconformity		
Hutchinsonian to Otaian	Oligocene	Mahoenui	500-700 ,,
Waitakian-Duntroonian		Te Kuiti	100-500 ,,
	Unconformity		
	Mesozoic	Greywackes and argillites	

* Use of the term "Group," for a rock unit, is in accordance with international usage: "Series" is better applied to groups of stages.

Disconformities separate, in one place or another, all the above formations.

The Wairere serpentinite lies in a zone of south-west faulting which separates the southern end of the Te Kuiti syncline of Tertiary rocks from the broadly anticlinal masses of Mesozoic greywackes and argillites with reduced Tertiary cover which culminate in the Herangi Range to the west. The Te Kuiti syncline (Marwick, 1946, p. 14) "is rather irregular and faulted in its south-western part," but is apparently represented by the shallow graben mapped by Grange (1927) between the Aria and Kaeaea faults in Aria Survey District.

The Aria fault has been mapped as breaking into a number of fractures in the south-west corner of the Totoro Survey District, immediately east of Wairere Falls, and the Wairere serpentinite is associated with the easternmost of these. In general, the Tertiary beds of the Te Kuiti syncline are relatively flat-bedded or gently dipping and undisturbed. In the comparatively narrow zone between the tectonic "low" of the Te Kuiti syncline and the tectonic "high" of the Herangi Range, however, somewhat steeper dips are mapped in a belt of faulting between these two major structures. The Wairere serpentinite mass lies in the plane of the easternmost of the several fractures east of Wairere falls, and its relations with the associated rocks may here be examined in detail (Fig. 2).

Relation Between Serpentinite and Sediments:

The splinters of Mesozoic greywacke mapped along the west side of the serpentinite have not been seen in contact with the igneous rock.

The Te Kuiti limestone which bounds the mass to the west is well-bedded, sometimes massively cemented, but usually jointed and flaggy. In three places where actual contacts with serpentinite are exposed the limestone becomes sandier and finally conglomeratic towards the contact. Two sections exposing the contact relations were examined, one near

cross section 10 ($2\frac{1}{2}$ chains north of the road) and the other at the entrance of the underground stream 21 chains north of the road. In both cases the bedding and contacts are vertical and the stratigraphical order in the limestone is from older beds on the east to younger beds on the west.

Contact near Cross Section 10.

Crystalline limestone with rare pebbles becoming sandier and more pebbly.

4ft. pebbly limestone becoming coarser and sheared against :

4 ft. puggy grey serpentinite, brecciated, passing into :

Dunite-serpentinite with augen of harzburgite-serpentinite

Contact at Underground Stream.

Crystalline massive limestone.

2 ft. rubbly brecciated limestone.

2 ft. 6 in. crushed conglomeratic limestone with serpentinite pug, filling irregular joints.

4 ft. brecciated serpentinite with fragments of crystalline limestone and rare water-worn pebbles, passing into :

Dunite serpentinite.

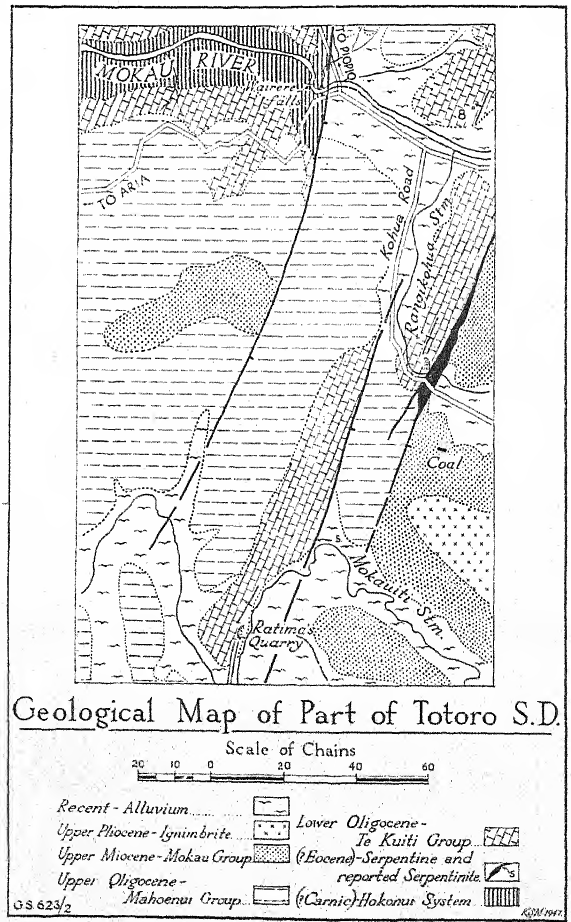


FIG. 2.—Geological map of part of Totoro S.D., to show relation of serpentinite to other rock groups. Geology by H. T. Ferrar and others (*N.Z. Geological Survey Bulletin 41*) with slight modifications.

North of the underground stream, fragments of gritty brecciated greywacke were noted adhering to the basal conglomeratic limestone.

In the first section detailed above, pebbles of greywacke, quartzite and argillite dominate in the conglomerate band, but there are also subangular but apparently water-worn serpentinite pebbles completely surrounded by crystalline limestone. In the second section, although pebbles of sedimentary rocks are abundant, quite a number of pebbles of serpentinite and gabbro showing some degree of rounding were identified.

The suggestion implicit in the above statements that the serpentinite antedates and is present as water-worn pebbles in the basal conglomerate of the Te Kuiti limestone is supported by Ongley's discovery, in 1919, of serpentinite pebbles in the basal conglomerate of the Te Kuiti limestone in the Mangaotaki Valley where that formation rests directly on the greywacke basement (personal communication). The interpretation of the sections at Wairere is, therefore, of a faulted and deformed depositional contact of the limestone upon the elongated splinter of serpentinite and greywacke which, together, are an up-faulted portion of the pre-Oligocene basement.

South of Kohua Road the limestone strikes away from the narrowing serpentinite ; there the dip is 30° steepening to 70° and the bedding shows a tight little over-turned anticline indicating pressure from the south-west. Still further south heavy scrub and a dearth of outcrops on the ridge between the Rangikohua and Mokauiti valleys obscures the relationship. In the Mokauiti Valley (Fig. 2) vertical limestone at Ratima's Quarry is faulted against Mahoenui beds on the downthrow side to the east and the Mahoenui beds in turn are faulted against Mokau sandstone by the southern end of the fault bounding the serpentinite of the Rangikohua Valley. The two short narrow zones of vertical limestone, one in the Rangikohua and the other in the Mokauiti Valley, have an echelon arrangement. There is a circumstantial report believed to be reliable that serpentinite is exposed in the Mokauiti at times of extreme low water at a point about 32 chains north east of Ratima's Quarry. A search at the spot in January, 1945, was unsuccessful, but the stream was flooded. If the report is substantiated the structural relations near Ratima's Quarry in the Mokauiti are comparable with those in the Rangikohua and have an important bearing on the interpretation of the geology.

North of the serpentinite mass the Te Kuiti limestone trends to the north-north-east with rapidly decreasing westward dip and is apparently faulted against the Mokau sandstones to the east without the intervention of serpentinite at the surface. For a mile the Mokau River follows the line of fault, and the dip of the limestone is 8° ; still further north the fault dies out and the limestone plunges gently beneath beds of the Mahoenui group.

If the serpentinite is older than the Duntroonian Te Kuiti limestone, it is almost certainly older than Whaingaroan since sediments of the latter age underlie the former beds to the north without evidence of substantial unconformity. As shown by Bartrum (1944), the North Auckland serpentinites appear to have intruded sediments as late as Bortonian (Middle Eocene). Following the hypothesis of Hess (1939) that if any one part of a peridotite belt can be dated the whole belt can be dated, the age of the Wairere serpentinite is taken as Upper Eocene, post-Bortonian and pre-Whaingaroan.

The age of the Te Kuiti limestone at Wairere is fixed as Duntroonian-Waitakian by a specimen of *Athlopecten athleta* (Zitt.) collected from the limestone immediately adjacent to the serpentinite. The same age is indicated by foraminiferal evidence presented in *Bulletin No. 41*, p. 44.

There are no clear sections to show the relations of the serpentinite with the Mokau group to the east. The evidence for considering this contact to dip at a relatively low angle to the east has been presented above and if a pre-Oligocene age for the serpentinite be accepted it follows that the contact with the Miocene Mokau beds to the east must be along a strong fault with a much greater throw than any fault which can be demonstrated on the west side of the serpentinite. In one pit sunk to explore the contact, grey puggy clay was separated from the hard serpentinite by a six inch reddish brecciated serpentinite pug. In another, the serpentinite surface fell in steps controlled by shear planes and finally plunged steeply beneath red-brown gritty serpentinous pug rapidly giving way to friable blue-grey mudstone. Other excavations immediately east of the serpentinite exposed rusty friable medium sandstone and siltstone with rare concretions.

In the road cutting half a mile east of the serpentinite, rusty finely bedded sandstones with flattish dip are exposed. In the centre of the graben to the south in Aria Survey District, the beds are mapped as essentially flat but dipping at moderate angles away from the Aria fault and in the accompanying sections the beds are sketched as dipping away from the serpentinite before they flatten (Fig. 3).

The late Dr. H. T. Ferrar's field sheet for Totoro S.E. Survey District shows an outcrop of Mokau coal up the slope south-east of the serpentinite which suggests that the rocks near the serpentinite belong to the Lower Mokau beds of Grange (1927, p. 17), below the coal horizon. Grange states that there are 350 ft. of Lower Mokau sandstones below the coal seams and associated beds and that 800 ft. of argillaceous sandstone overlying 265 ft. of coal-measures comprise the Upper Mokau beds. Marwick (1946, p. 53) states that the thinning of the Lower Mokau beds towards the east, noted by Grange, holds also towards the north " for in Te Kuiti Subdivision the coal-measures when present, appear to be low in the series." In the section, therefore, the base of the Mokau group is drawn not far below the surface. Judging by the average thickness of the Tertiary formations in the area (Marwick, 1946) the thrust fault east of the serpentinite has a throw of 700-1,000 ft. However, as disconformities are reported between the several formations and the thicknesses are stated to vary considerably, this estimate must be regarded as an approximation only.

There remains some doubt as to the stages represented by the deposition of the widespread arenaceous beds which have been mapped as " Mokau ". In their type development near the coast, the Mokau beds are apparently coeval with the Waitemata and Ihungia beds of other areas and of Altonian age (Finlay and Marwick, 1947, p. 229). Elsewhere " inland Mokau " beds (which include those in the Wairere area), have faunas of low Taranakian (Finlay, in Marwick, 1945, p. 57) and Taranakian age (Gage, 1942, p. 128B). Apparently there is widespread overlap of beds in an inland direction, and the Mokau transgression occupied much of the Miocene period. It is certain that a marked stratigraphic break exists between the Mahoenui and Mokau beds and this break is represented by angular unconformity in the upper Wanganui (Superior Oil Company : The Geology of the Palmerston-Wanganui Basin, 1943).

Samples submitted to Dr. H. J. Finlay for foraminiferal determinations contained only non-diagnostic species, but the presence of volcanic glass in the residue perhaps points to an Upper Miocene (Mohakatino) age.

The Mahoenui group has been mapped on a purely lithological basis to the south of the serpentinite where leucocratic claystones and mudstones were exposed in the prospecting pits to a depth of 14 ft. Such fine-grained sediments are characteristic of the Mahoenui beds of the district and are unusal in other formations. Samples collected for foraminifera were unfortunately non-diagnostic. Where the contact with serpentinite was seen, a variable thickness of gritty brecciated and leached serpentinous material intervened between hard serpentinite and red-stained plastic clay, which was lighter and non-plastic away from the contact. The strike of shear planes and plunging surfaces in the serpentinite tends to swing from the usual north-east direction to a more northerly trend following the contact of the body with the supposedly Mahoenui rocks at depth. The wedge of Mahoenui rocks is interpreted, with some diffidence, as down-faulted against both the Te Kuiti limestone to the west and the serpentinite to the north-east, that is, the fault which juxtaposes Mokau and Te Kuiti beds on either side of the serpentinite to the north is believed to have broken south of the serpentinite into two stepped fractures of similar sense but lesser throw.

Structure :

The section presented as Fig. 3 is based upon the surface relationships revealed by the prospecting and utilizes known stratigraphic relations in the area from information in *Geological Survey Bulletins 31* and *41*. The subsurface form of the serpentinite is hypothetical.

Two alternative hypotheses may be advanced to explain the complex structural relationships. One hypothesis involves faulting of an earlier asymmetrical fold, the other invokes the mechanism of diapir folding.

Both hypotheses allow that a serpentinite intrusion in Mesozoic sediments had been exposed to erosion prior to the Oligocene marine transgression and that its present relations to the Tertiary beds it penetrates, are the result of post-intrusive differential movement.

The first hypothesis involves the derivation of the structure by later faulting of an asymmetrical anticline the axis of which lay on the line of a serpentinite intrusion in the Mesozoic basement. To satisfy the structural requirements of the sections the differential movement in a later faulting stage must have been in the opposite sense from that in the earlier folding movement. Reversal of movement along faults is, of course, well established in many areas, and it is quite conceivable that the Te Kuiti area may have suffered an earlier, post-Waitakian, phase of folding prior to the last (post-Taranakian, pre-Nukumaruan *fide* Marwick, 1946, p. 11) major deformation to which most of the faulting in the area is attributed. The several stratigraphic breaks in the Miocene sequence and, particularly, the unconformity of the Mokau beds on the Mahoenui make such a hypothesis reasonable.

On the other hand no such complexity of fault and fold movements has been noted in the Te Kuiti and adjacent Tongaporutu-Ohura Subdivision, and the hypothesis requires an east dipping fault plane, whereas Grange (1927, p. 9) described all other fractures of the same system further south, as dipping steeply west.

The Western Tertiary basin from Auckland to North Taranaki has, on the whole, suffered only gentle folding and faulting of moderate intensity, there is a notable absence, over an appreciable area, of the strongly compressional tectonic forms such as characterize for example the " mobile belt " regions of East Wellington and Hawke's Bay. For this reason the association of serpentinite masses with the steepest dipping Tertiary beds in the entire Te Kuiti area appears to the writer strongly suggestive of the operation of special tectonic processes directly related to the presence of the serpentinite. It is surely too much of a coincidence for the axes of intense and strictly local deformation to be immediately over the position

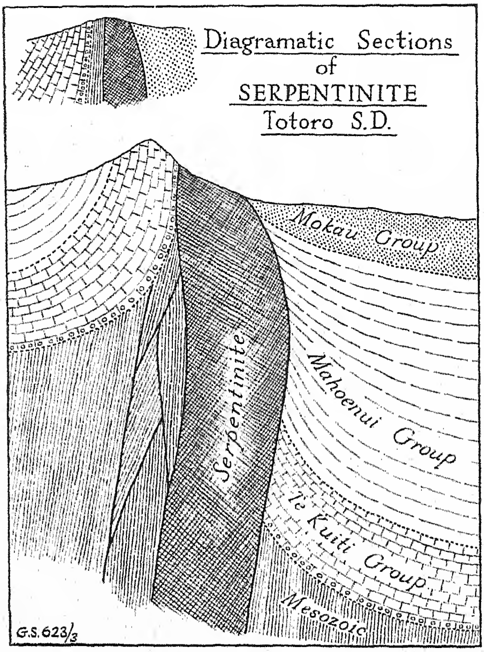


FIG. 3.

of equally local serpentinite bodies in the basement unless there is some causal relation between the two phenomena. As an alternative to the hypothesis outlined above, therefore, an explanation is offered which relates the deformation of the Tertiary cover directly to the upward movement of a mobile serpentinite mass in a manner comparable to the diapir folding advocated as the mechanism of salt dome and associated structures in the Caucasus, Germany and North America. Diapiric structure (Mrazec, 1910) is the name given to anticlinal folds in which the core penetrates overlying beds ; such structure is " . . . . dependent on movements principally in the upward direction " (Bolidanowicz, 1932). The mechanism of diapirism is perhaps the most popular way of explaining salt dome intrusions in which rupture of cover-beds has been demonstrated (Barton, 1925, Voitesti, 1925, Bolidanowicz, 1932, Plimmer, 1923). The core material of a diapir is usually a substance capable of semiplastic movement when deformed, such as salt or gypsum. Diapiric upthrusts of the salt dome type seem to be related as much to the differences in competence of the core and country rock as to acuteness of orogenic deformation ; in Roumania such structures may be motivated

by orogenic thrust, but " the general region in which the American salt domes occur has been one of great geologic tranquility " and " from the salt domes . . . . . . it is far to any region which shows the traces of compressive folding " (Barton, *op. cit.* p. 1265).

It may be suggested that serpentinite is a substance capable of behaviour similar to that of salt and gypsum in the cores of diapir folds. The close-set slickensided shear planes characteristic of all North Island serpentinites bear witness to appreciable movement within the serpentinite bodies, and no case has yet been described where the contacts of serpentinite with the strata which surround them are anything but faulted and sheared zones showing signs of appreciable movement. The occurrence of lenticular *augen* of relatively unsheared harzburgite or gabbro elongated parallel to the dominant direction of shearing also points to appreciable differential movement within such serpentinite masses, since such magmatic differentiates almost certainly once formed continuous dyke-like sheets or pipes within a dominantly dunite intrusion. The process of serpentinization of dunite is usually interpreted as involving a decided increase in volume, though the theory of Hess (1933) accounts for the process without volume increase. Assuming the intrusion to have been more or less in a state of equilibrium with the surrounding rocks when serpentinization began, any increase in volume during serpentinization would tend to take the direction of least pressure, that is, in general, upwards. Even if no important volume changes are involved in post-magmatic changes (and Hess's theory of serpentinization is attractive in that it avoids such changes) it is not difficult to imagine that relatively small orogenic compressive forces acting on a comparatively incompetent and potentially mobile serpentinite intrusion might induce the dyke material to yield and move upwards through a comparatively thin and unresistant Tertiary cover.

The fact that the Wairere serpentinite shows little sign of intense shearing, in the absence of minerals such as antigorite and talc, may not be prejudicial to the conclusion that appreciable movement has occurred, for such stress minerals are unlikely to have formed in the relatively superficial zone in which any movement of the serpentinite has taken place. The maximum thickness of Tertiary cover overlying the serpentinite during the period when the postulated movements took place is between 1,300 and 3,500 ft.—probably nearer the former than the latter figure.

The second hypothesis invokes a diapiric arching and rupture of the Tertiary cover through the upward thrusting of a serpentinite core extruded out of the Mesozoic basement in which the serpentinite originally had the form of a sill in steeply west-dipping bedding planes. The hypothesis assumes that a late Tertiary fracture at the position of the serpentinite downfaulted beds to the east ; that the fault plane was steeply west dipping in response to a certain degree of overthrust from the west ; and that the diapiric upward movement of the serpentinite was merely a particular response of that substance to deformative stresses no more acute than elsewhere in the district. The hypothesis explains the occurrence of upturned beds on the upthrow side of the fault and also the east-dip of the eastern faulted contact in an area of west-dipping faults. The quarrying operations at Wairere may be expected to provide more evidence for the solution of the problem, and in the meantime the hypothetical nature of such an explanation is appreciated, and no further space need be devoted to the several possible variations of a diapiric mechanism.

Since the above was written an important paper by N. L. Taliaferro (1943) on the Franciscan-Knoxville problem has been perused. Taliaferro has described cold intrusions of serpentinite of Jurassic age which have penetrated overlying Cretaceous to Miocene sediments and form the cores of faulted anticlines in much the same way as is postulated in the case of the Wairere serpentinite.

The serpentinite is elongated in the direction of the strike of the steep west-dipping limb of the Mesozoic syncline of the Herangi range (Marwick, 1945, p. 26) a syncline which had begun to behave as an anticline by at least Oligocene times*. The serpentinite was apparently injected in the Eocene near the " hinge line " between a Mesozoic syncline becoming anticlinal and a possibly Mesozoic anticline, not yet fully demonstrated, later becoming synclinal (Te Kuiti syncline). Later (Post-Miocene) stresses caused faulting at the " hinge line " and the serpentinite of the earlier orogenic phase became involved in the movements of the later phase. Hess's (1939) conclusion that peridotite injection is related to the first deformation of a mountain system in the " island arc " stage might be applied to the early Tertiary foreshadowing of the post-Miocene orogenic pattern in the Te Kuiti area.

REFERENCES

BARTON, D. C. (1925): The American Salt Dome Problems in the light of the German Salt Domes. *Bull. Am. Ass. Pet. Geol.*, *9*, 1227-68.

BARTRUM, J. (1944): Recent Petrographic Discoveries in the Silverdale-Wellsford Area, Auckland. *N.Z. J. Sci. and Tech.*, *16*, 28-35.

BARTRUM, J. and TURNER, F. (1928): Pillow-Lavas, Peridotites and Associated Rocks of Northernmost New Zealand. *Trans. N.Z. Inst.*, *59*, 98-138.

BENSON, W. N. (1944): The Basic Igneous Rocks of Eastern Otago and their Tectonic Environment. Part IV, *Trans, Roy. Soc. N.Z.*, *74*, 71-123.

BOLIDANOWICZ, K. (1932): Geology and Mining of Petroleum in Poland. *Bull. Am. Ass. Pet. Geol.*, *16*, 1061-91.

FINLAY, H. J. and MARWICK, J. (1947): New Divisions of the New Zealand Upper Cretaceous and Tertiary. *N.Z. J. Sci. and Tech.*, *28*, (*Sec. B*), 228-36.

GAGE, M. (1942): The Mangapehi Coal Measures and Associated Strata. *N.Z. J. Sci. and Tech.*, *23*, 126B-31B.

GRANGE, L. I. (1927): The Geology of the Tongaporutu-Ohura Subdivision. *N.Z. Geol. Surv. Bull.*, *31.*

HENDERSON, J. and ONGLEY, M. (1923): The Geology of the Mokau Subdivision. *N.Z. Geol. Surv. Bull.*, *24.*

HESS, H. H. (1933): The Problem of Serpentinisation and the Origin of Certain Chrysotile Asbestos, Talc, and Soapstone Deposits. *Econ. Geol.*, *28*, 634.

——— (1939): Island Arcs, Gravity Anomalies and Serpentine Intrusions. *Internat. Geol. Congr. XVII, U.S.S.R. Rept.*, *2*, 279-300.

HUTTON, C. O. (1936): Basic and Ultrabasic Rocks in North-west Otago. *Trans. N.Z. Inst.*, *66*, 231-45.

MARWICK, J. (1946): The Geology of the Te Kuiti Subdivision. *N.Z. Geol. Surv. Bull.*, *41.*

PLIMMER, H. (1923): "Les Gisements de Petrole" by J. Chaulard (Review). *Bull, Am. Ass. Pet. Geol.*, 7, 582-84.

SUPERIOR OIL CO. (1943): The Geology of the Palmerston-Wanganui Basin. (Typescript report filed at Mines Dept., Wellington.)

TALIAFERRO, N. L. (1943): Franciscan-Knoxville Problem. *Bull. Am. Ass. Petr. Geol.*, *27*, 109-219

* The Te Kuiti limestone is missing from a large central area of the range where Mahoenui beds rest directly upon the basement.

TERTIARY ROCKS AT MARBLE POINT, WAIAU RIVER, NORTH CANTERBURY

By BRIAN MASON, Canterbury University College, Christchurch

(*Received for publication, 4th August, 1947*)

THE so-called Hanmer marble is widely known and extensively used throughout New Zealand on account of its handsome red colour. The locality at which it is worked, Marble Point, on the Waiau River, is also familiar to many, as it is alongside the main highway from Canterbury to Nelson and Westland via the Lewis Pass (Fig. 1). In spite of this,

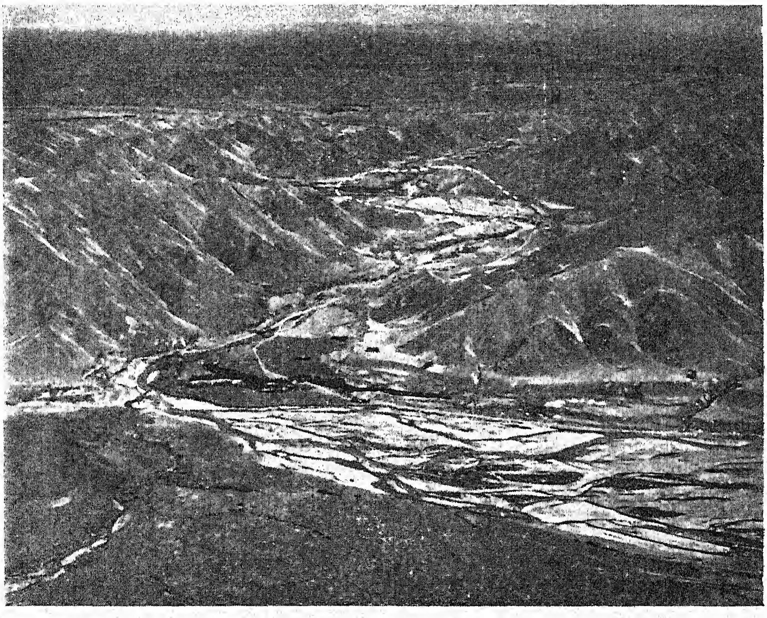


FIG. 1.—Aerial view looking down the Waiau Gorge. The area of Tertiary rocks is outlined in white. The Waiau River flows from right to left across the photo. The road junction in the middle of the photo is that of the Hanmer road (left) and the Lewis Pass road (right). [V. C. Browne, *photo*.

only incidental reference to the locality is to be found in geological literature. In view of the fact that the limestone is only one member of an extensive and well-exposed Tertiary sequence, and a visit to the locality is an easy and pleasant day's excursion from Christchurch, the occurrence was considered worthy of this brief description.

Marble Point is some fifteen miles from Culverden by road (the homestead belonging to the station of the same name is two miles nearer Culverden than Marble Point itself). From Marble Point the limestone strikes directly across the Waiau River, and the river splits around an island of limestone, known as Garden Islet (Fig. 2). The Tertiary rocks are exposed along the river for a total length of somewhat more than a mile. Away from the riverbed only the limestone outcrops are seen, the

other beds in the sequence being covered by a heavy deposit of terrace gravel. The information in this paper is based on a detailed examination of the section on the right bank of the Waiau (looking downstream). The Tertiary rocks extend across the river to the left bank and beyond for some distance. To reach the left bank at this point necessitates either swimming the river or travelling across country for some miles from the traffic bridge at Waiau Ferry. From the right bank the sequence on the opposite bank was seen to be similar, but not so well exposed.

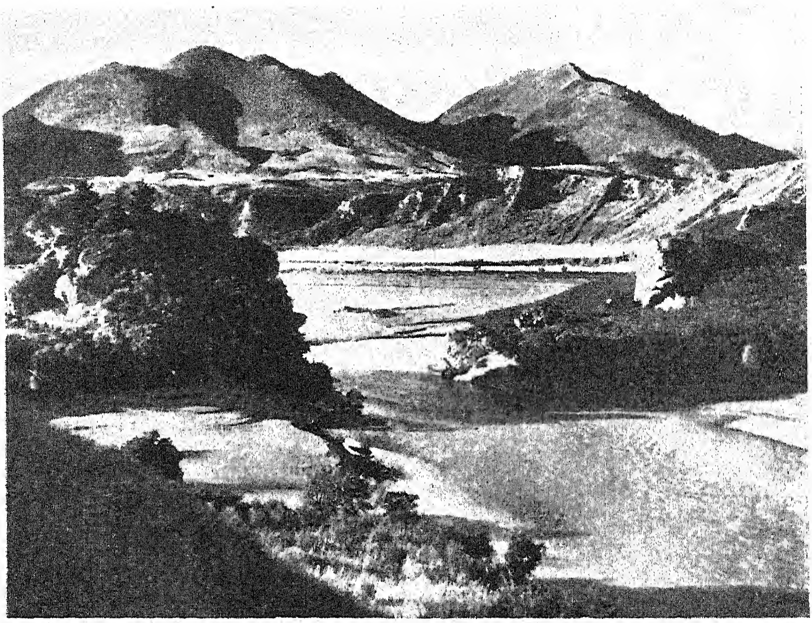


FIG. 2.—Looking upriver from Marble Point. Garden Islet is in the left foreground with the limestone, here nearly vertical, striking across the river. A small outcrop of hard glauconite sandstone shows in the riverbed just beyond. The undulating bench in the middle distance is cut in soft Lower Tertiary sandstone, and the hills in the background are of greywacke. [V. C. Browne, *photo.*

The Tertiary rocks at Marble Point are completely surrounded by and deeply involved in pre-Tertiary greywackes and argillites. No detailed examination of the structural features of this inlier was made, but the section along the river indicates a normal sequence when going from the northern (upstream) end, terminated downstream by a high-angle reverse fault which brings greywacke into contact with Middle Tertiary (Waitakian) beds. Evidently the pre-Tertiary rocks have been thrust from the south over the Tertiary beds. The total area of the Tertiary inlier is quite small—of the order of a few hundred acres in all.

The lowest Tertiary beds are exposed about 50 chains upriver from Garden Islet. The sequence commences with a basal conglomerate about 60 ft. thick. This conglomerate rests on a coarse somewhat friable sandstone which is evidently a much leached and weathered greywacke, probably an ancient land surface. The conglomerate consists

of well-rounded pebbles up to 4 in. in diameter ; they consist mainly of greywacke, but some are of porphyritic igneous rocks, similar to the sills known in the Mandamus-Pahau area (Mason (in the press)). The pebbles are very decomposed, and can be crushed between the fingers. The conglomerate is calcareous in places, and contains coal fragments at the top. Samples of finer material from the conglomerate were submitted to Dr. Finlay, who reports a fair fauna from the highest sample, indicating Mangaorapan age.

The conglomerate is exposed for about 20 yd. on the river bank, and is succeeded by a soft grey calcareous glauconitic mudstone which becomes gradually sandier when followed downstream. It is continuously exposed for about 500 yd., beyond which the sequence is obscured by river gravels for 400-500 yd., practically down to Garden Islet. There is an isolated outcrop of hard glauconitic sandstone in the river itself about 200 yd. above Garden Islet (Fig. 2), and the section which begins again just above Garden Islet is continuous downstream to the fault contact with the greywacke. At Garden Islet the lowest outcrop is of soft green-grey calcareous very glauconitic sandstone, similar to the material further upstream. This is overlain by about 50 ft. of greenish bedded tuff, followed by 50 ft. of pillow lava ; the pillow lava is not well exposed on the right bank, but is clearly seen immediately across the river. The pillow lava is succeeded by about 100 ft. of red bedded tuff, coarse at the base but becoming finer in the upper part ; at the base of this red tuff a specimen of the brachiopod *Liothyrella boehmi* Thomson was collected, this being the only macrofossil found apart from indeterminable fragments of mollusc and brachiopod shells in the limestone. The red tuff is succeeded by limestone, the so-called Hanmer marble, which is worked in the quarry alongside the road. This limestone is about 80 ft. thick and owes its characteristic red colour to the admixture of fine-grained tuff; the finest red stone comes from the lower part of the limestone, and hence the colour falls off in the upper part, which is pale pink or cream-coloured.

The dip, which is 60°-75° further upstream, becomes vertical at Garden Islet, and below this island the sequence is complicated, evidently on account of close folding of the beds against the fault which terminates them. The limestone which forms Garden Islet is succeeded by a moderately soft grey calcareous sandstone ; the sequence is then limestone, tuffs, limestone, sandstone, and tuffs. The highest bed in the sequence is the sandstone, and repetition of the beds is brought about by close folding. That the limestone is strongly folded is clearly shown by the form of the outcrops along the main road and near the quarry ; here it appears to form a sharp syncline pitching steeply towards the river.

The succession of beds, and their age relationships as indicated by the foraminifera faunas, is shown in the stratigraphical column (Fig. 3). The sequence is exactly parallel with that in the Pahau-Mandamus area about eight miles to the southwest (Mason (in the press)). The basal conglomerate is Mangaorapan, and is succeeded by a glauconitic mudstone which is also Mangaorapan. This mudstone grades up into a grey sandstone of considerable thickness, probably about 400 ft. A sample from low in the sandstone gave a very small fauna, which Dr. Finlay considers to be probably Heretaungan. Unfortunately, samples

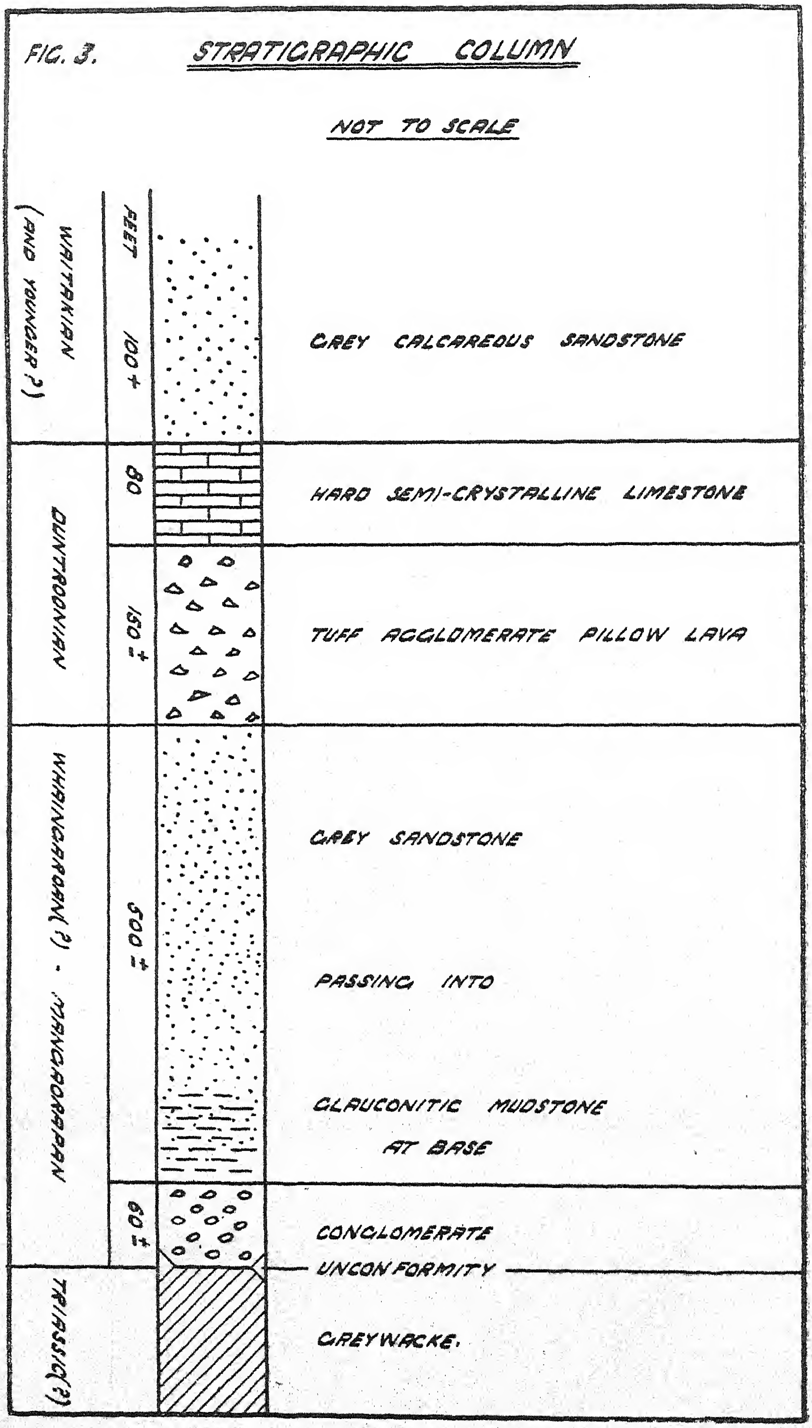


FIG. 3.—Stratigraphic column for the sequence at Marble Point.

higher in the sandstone were barren of foraminifera, but by analogy with similar beds in the Pahau area higher horizons up to Whaingaroan may well be present. The sandstones are overlain by tuffs, pillow lava, and basaltic agglomerate, followed by the limestone. Samples from the tuffs and the limestone did not yield foraminifera but the corresponding beds in the Pahau area are of Duntroonian age. The grey calcareous sandstones which overlie the limestone gave poorly preserved faunas indicating probable Waitakian age.

The section at Marble Point adds a further link to the chain of evidence that has been accumulating for a widespread overlap at the base of the Tertiary in North Canterbury. Examination of numerous sections throughout North Canterbury, and Dr. Finlay's age determinations on the basis of the foraminifera faunas, indicates that Upper Cretaceous rocks are absent over a wide area, approximately north of a line through Waikari and Scargill and west of a line through Scargill and Waiau. In all the sections examined within this region the sequence begins with Mangaorapan beds, generally a glauconitic mudstone with or without an underlying basal conglomerate. Another uniform feature of this region is the absence of the typical Amuri limestone, otherwise so prominent and widespread in the North Canterbury landscape. In this region the horizon of the Amuri limestone is represented by sandstones, often comparatively coarse. (By a curious geographic anomaly there is apparently no Amuri limestone within Amuri County.) Over a large part of this area, too, coarse submarine volcanics and semi-crystalline limestone (the Cookson series and Isolated Hill Limestone of Fyfe (1931)) replace the Weka Pass Stone. All these features—the post-Cretaceous transgression, the shallow-water nature of the Eocene and Oligocene beds, and the submarine volcanism—are presumably related to the situation of this area along the north-western margin of what was probably a slowly subsiding shelf undergoing marine deposition.

ACKNOWLEDGMENTS

I would like to express my appreciation to my brother Mr. A. P. Mason, for his company and assistance in the field, and to Dr. H. J. Finlay, of the New Zealand Geological Survey, for the examination of several samples for foraminifera.

REFERENCES

FYFE, H. E. (1931): Amuri Subdivision, *N.Z. Geol. Surv., 25th Ann. Rept.*, p. 5-6.

MASON, B.: *Trans. Roy. Soc., N.Z.*, (In the press).

TERTIARY STRATA AT COAL CREEK, RANGITATA RIVER

By BRIAN MASON, Canterbury University College

(*Received for publication, 4th August, 1947*)

INTRODUCTION

TERTIARY rocks have long been known to occur at Coal Creek in the upper basin of the Rangitata River, but no detailed description of the stratigraphy has been published, although brief mention has been made in a number of papers, the latest in that by Professor Speight on the Rangitata Glacier (1941). A rapid examination of this occurrence was made in January, 1947, and in view of the good sequence there exposed and its geographical position between the well-known Mt. Somers district to the north and the Kakahu district further south, it was deemed worthy of a more detailed description.

The Tertiary rocks occur as a narrow strip about four miles long and up to a mile wide extending south-east from the lower part of Coal Creek where it joins the Rangitata River on the south bank to the valley of Boundary Creek and beyond for some distance. The rocks themselves are exposed only in the banks of Coal Creek and Boundary Creek and along the road in the vicinity of Whiterock station ; elsewhere they are obscured by vegetation and a cover of moraine and gravel. This strip of Tertiary rocks forms a well-marked topographic depression at an altitude of about 2,000 ft., bounded by a continuation of the Mt. Peel block to the south-west and by a chain of lower hills to the north-east. The road to Mesopotamia station follows this topographic depression and provides easy access to this patch of Tertiary rocks, Coal Creek being about 27 miles from Geraldine.

STRUCTURE

This strip of Tertiary rocks has been preserved by being down-faulted along the powerful fault which bounds the Mt. Peel block on the north-east. The line of this fault is seen in Coal Creek and Boundary Creek, where the Tertiary rocks end against much shattered greywacke. The fault is probably a high-angle reverse one. It is slightly oblique to the strike of the Tertiary rocks. The Tertiary rocks form an accordant sequence and dip at moderate angles into the fault angle from the block to the north-east, which shows a little-dissected stripped surface where the Tertiary rocks have been removed by erosion.

STRATIGRAPHY

The succession of beds in this area is illustrated by the stratigraphic columns for the sections exposed in Coal Creek and in Boundary Creek, (Fig. 1) and the composite section for the sequence as a whole (Fig. 2). Neither in Coal Creek nor in Boundary Creek is the complete sequence exposed, but the incomplete sections can be combined to give an adequate picture of the whole succession.

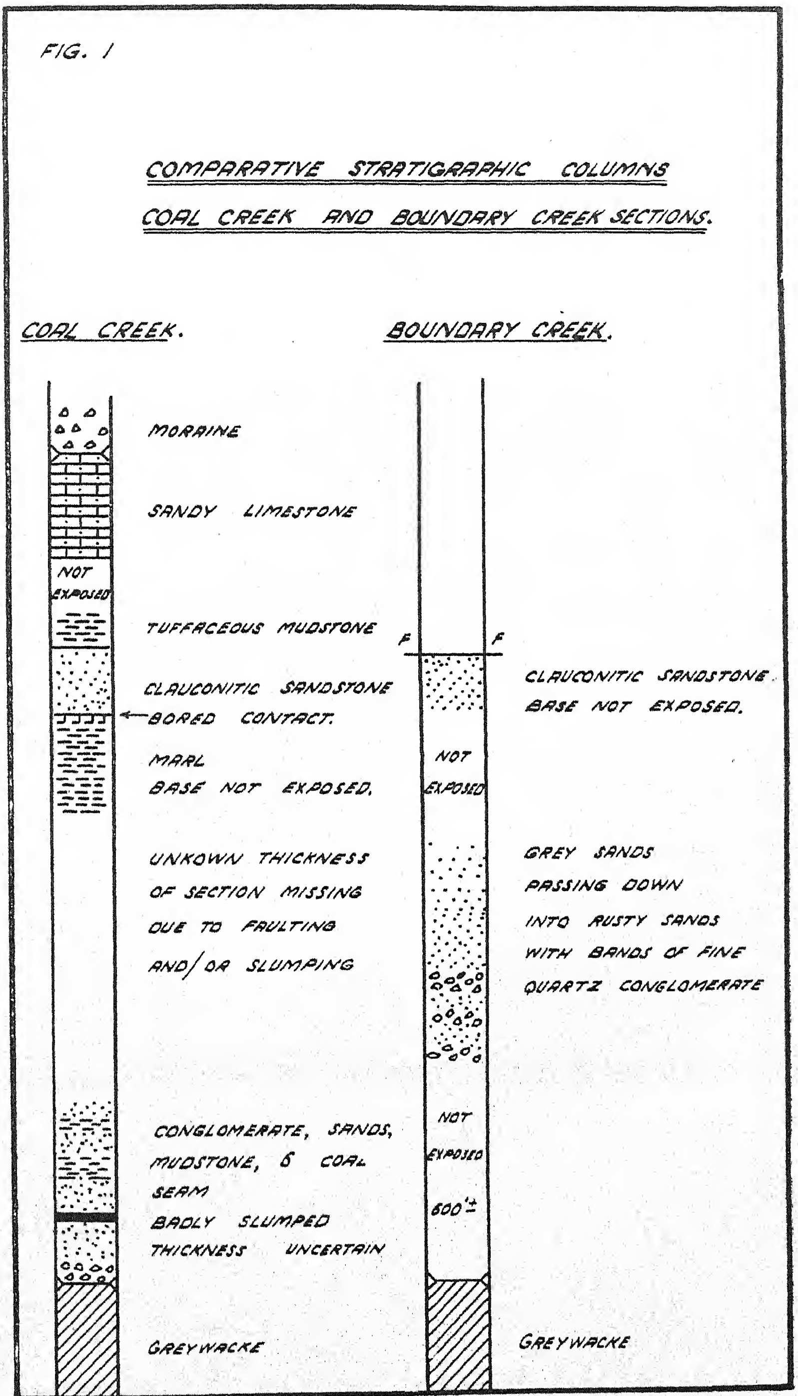


FIG. 1
COMPARATIVE STRATIGRAPHIC COLUMNS
COAL CREEK AND BOUNDARY CREEK SECTIONS.
COAL CREEK.
BOUNDARY CREEK.
MORAINE
SANDY LIMESTONE
NOT EXPOSED
TUFFACEOUS MUDSTONE
CLAUCONITIC SANDSTONE
BORED CONTACT.
MARL
BASE NOT EXPOSED.
UNKOWN THICKNESS
OF SECTION MISSING
DUE TO FAULTING
AND/OR SLUMPING
CONGLOMERATE, SANDS,
MUDSTONE, & COAL
SEAM
BADLY SLUMPED
THICKNESS UNCERTAIN
GREYWACKE
F F
CLAUCONITIC SANDSTONE.
BASE NOT EXPOSED.
NOT EXPOSED
GREY SANDS
PASSING DOWN
INTO RUSTY SANDS
WITH BANDS OF FINE
QUARTZ CONGLOMERATE
NOT EXPOSED
600'±
GREYWACKE

Fig. 1

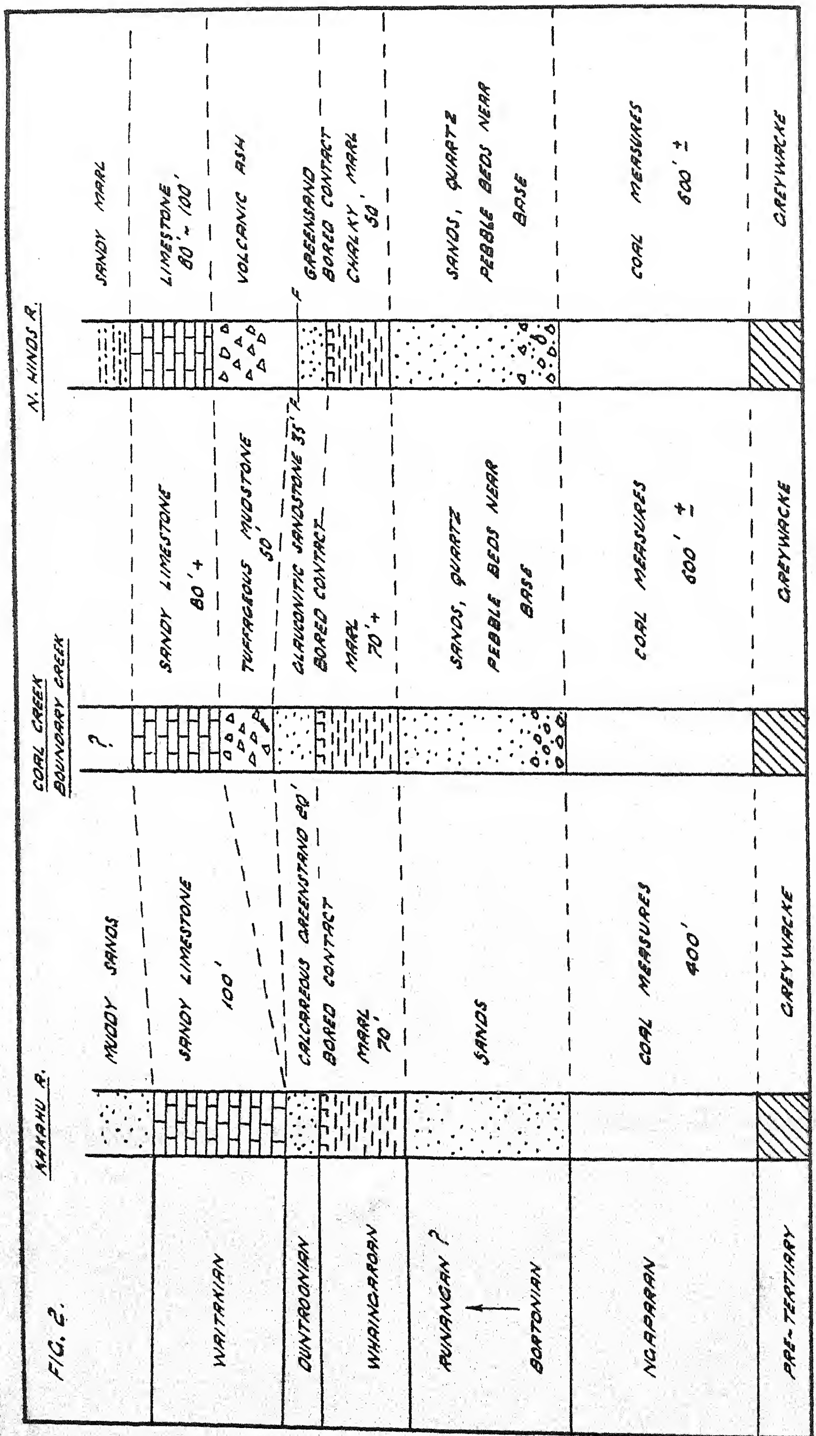


FIG. 2.
KAKAHU R.
CORAL CREEK
BOUNDARY CREEK
N. HINDS R.
WAITAKIAN
DUNTROONIAN
WHAINGAROAN
RUNANGAN ?
BORTONIAN
NGAPARAN
PRE-TERTIARY
MUDDY SANDS
SANDY LIMESTONE
100'
CALCAREOUS GREENSAND 20'
BORED CONTACT
MARL
70'
SANDS
COAL MEASURES
400'
GREYWACKE
?
SANDY LIMESTONE
80' +
TUFFACEOUS MUDSTONE
50'
GLAUCONITIC SANDSTONE 35'
BORED CONTACT
MARL
70' +
SANDS, QUARTZ
PEBBLE BEDS NEAR
BASE
COAL MEASURES
600' ±
GREYWACKE
SANDY MARL
LIMESTONE
80' - 100'
VOLCANIC ASH
GREENSAND
BORED CONTACT
CHALKY MARL
50'
SANDS, QUARTZ
PEBBLE BEDS NEAR
BASE
COAL MEASURES
600' ±
GREYWACKE

FIG. 2

The lowermost beds are coal measures, which are exposed in Coal Creek, but which are so badly slumped that it is not possible to make out the detailed sequence. The lowest bed exposed is a conglomerate with well-rounded pebbles up to 2 in. in diameter set in a greyish white sandy matrix. The pebbles in this conglomerate are mainly of rotted greywacke, but include a hard black horny rock, rare quartz pebbles, and very rare chalcedony pebbles, with occasional coaly fragments. Above the conglomerate the succession includes pink and grey silty clay, grey and white quartz sands, and a seam of coal up to 6 ft. thick. The quartz sands are occasionally cemented into a hard quartzite which contains poorly preserved plant remains. I understand that some coal has been mined here by local station owners for their own use. It is a lignite, similar to that at Mt. Somers.

The sequence in Coal Creek is interrupted above the coal measures, the next formation to be seen there being the Whaingaroan marl. In Boundary Creek the coal measures are probably present, but are not exposed, and the first outcrops are of rusty sands with bands of fine quartz conglomerate, some of the bands of quartz conglomerate containing molluscan fossils. The following genera and species have been identified by Mr. C. A. Fleming of the New Zealand Geological Survey :—

Cucullaea sp.
Crassatellites cf. *australis* (Hutton).
Ostrea cf. *sinuata* Lk.
Venericardia (*Cyclocardia*)? aff. *Pseutella* (Marwick).
Hedecardium cf. *waitakiensis* Suter.
Dosinia sp.
Sigapatella sp.

Of this collection Mr. Fleming writes : " A poorly preserved fauna. *Crassatellites australis* is typically Bortonian. The sub-genus *Cyclocardia* seems to begin about Whaingaroan, and the *Hedecardium* is not the Bortonian *brunneri* but larger, like the Duntroonian assemblage. Bortonian to Duntroonian, possibly about Whaingaroan."

As the beds from which these fossils were collected are considerably lower in the sequence than the overlying Whaingaroan marl, it is considered that the fauna is likely to be older than Whaingaroan, and the beds from which it came are tentatively classed as Bortonian, on the fossil evidence and the lithologic similarity with beds of definite Bortonian age in the Mt. Somers and Kakahu districts.

The rusty sands pass up into grey quartz sands which are unfossiliferous and may represent a higher horizon.

At this point there is a gap in the sequence in Boundary Creek due to lack of exposures. In Coal Creek a hard light grey marl occurs at this horizon. Its base was not seen, but about 70 ft. is exposed before the formation is terminated by a strongly bored surface, the borings being up to 2 ft. deep and filled with the overlying glauconitic sandstone. This contact is entirely similar to the bored surface at the top of the Amuri limestone in North Canterbury, and occurs at the same stratigraphical horizon. Samples submitted to Dr. H. J. Finlay gave foraminifera faunas showing that the marl is Whaingaroan and the overlying glauconitic sandstone Duntroonian or Waitakian. Samples from the

bored zone itself yielded battered foraminifera probably derived from the underlying marl. A sample from the lowest outcrop of glauconitic sandstone exposed in Boundary Creek gave a similar fauna, whereas a higher sample from the same locality gave a poor fauna either of Duntroonian or Waitakian age but without derived Whaingaroan forms.

The next formation, exposed both in Coal Creek and Boundary Creek, is a moderately soft grey glauconitic sandstone. At the base where it is exposed in Coal Creek it contains numerous perfectly preserved specimens of *Lentipecten hochstetteri* (Zittel). In Boundary Creek the base is not exposed, but the foraminifera fauna from the lowest outcrop there suggest that it is very close to the underlying formation ; the top is also not seen at this locality, as the formation ends with a fault contact against the greywacke. The full thickness of the formation, some 30 ft., is however exposed in Coal Creek, and the top has a sharp but regular contact with the overlying formation, a hard dark grey tuffaceous mudstone. Samples from the glauconitic sandstone gave poor foraminifera faunas for which Dr. Finlay suggests Waitakian or Duntroonian age. On stratigraphic grounds a Duntroonian age is preferred.

The hard dark grey tuffaceous mudstone is well bedded and strongly jointed, and breaks up readily into small angular fragments. No macrofossils were seen, and samples were barren of foraminifera. It evidently represents a brief period during which fine-grained volcanic ash was washed into the area, probably from the Mt. Somers district to the north-east where volcanic activity was marked at that time. Only 15 ft. of the tuffaceous mudstone is exposed in Coal Creek, and the total thickness cannot be very great, probably not more than 50 ft.

The next formation is a moderately hard cream coloured glauconitic sandy limestone. Neither the top nor the base of this formation is exposed, but a thickness of about 80 ft. was measured, and the total thickness is unlikely to be very much greater. No macrofossils were seen, but samples submitted to Dr. Finlay gave poor foraminifera faunas which he reports as probably Waitakian.

This limestone is the highest bed seen in the Tertiary succession here. It is possible that higher beds may be present under the cover of gravel and moraine between the limestone and the fault cutting off the Tertiary rocks against the greywacke, but no exposures were found.

COMPARISON WITH ADJACENT AREAS

The nearest described sequences with which this succession may be compared are in the North Hinds River to the north-east (Speight 1938) and at Kakahu to the south (Maling, unpublished thesis, and Wellman, private communication). Stratigraphic columns for these three sequences are given in Fig. 2.

Fig. 2 shows that the succession is closely similar in the three localities. An interesting feature is the change from volcanic ash below the limestone in the North Hinds River to a tuffaceous mudstone at Coal Creek, and then the complete absence of volcanic material in the Kakahu succession. Evidently the Mt. Somers district was the centre of volcanic activity in Duntroonian-Waitakian times; some of the ash was carried as far as the Coal Creek area and incorporated in the mudstone being deposited there, but this igneous material did not extend as far as the Kakahu district.

ACKNOWLEDGMENTS

I would like to express my appreciation to my brother, Mr. A. P. Mason, for his company and assistance in the field; to Dr. H. J. Finlay and Mr. C. A. Fleming for their palaeontological determinations; to Mr. H. W. Wellman, for permission to use the results of some of his work in the Kakahu district; and to the staff of the Coal Survey, for the analysis of the coal from this area, which is given as an appendix.

REFERENCES

SPEIGHT, R. (1938): The Geology of the Mount Somers District. *N.Z. Geol. Surv. Geol. Memoir 3.*

SPEIGHT, R. (1941): The Rangitata Glacier—The Question of Its Maximum Extension. *Trans. Roy. Soc. N.Z., 71*, 169-80.

APPENDIX

A sample of the coal from an outcrop in Coal Creek (Grid Reference: 695/295, Sheet S91, Mt. Peel) was sent to the Coal Survey Laboratory, Wellington, and analysed with the following results:

Laboratory No. CS 1569

Proximate Analysis (on air dried coal)

Moisture	18.3
Volatile Matter	37.5
Fixed Carbon	41.4
Ash	2.8

Calorific Value 9,510 B.Th.U./lb.

Sulphur 1.7 per cent.

Ultimate Analysis (calculated to dry, ash-free coal)

Carbon	70.2
Hydrogen	5.0
Nitrogen	0.4
Sulphur	2.1
Oxygen	22.3

MEASUREMENT OF EXPLOSION SHOCK ON A CONCRETE PIER

By L. BASTINGS, Dominion Physical Laboratory, Department of Scientific and Industrial Research

(*Received for publication, 2nd July, 1947*)

Summary

Measurements carried out with very simple apparatus on the effect of an underwater explosion on a nearby concrete pier are shown to be capable of yielding significant information regarding the magnitude of the shock suffered by the pier. The bearing of this experiment upon engineering aspects of earthquakes is discussed.

ON July 13th, 1944, the Naval authorities exploded a number of groups of underwater mines in the entrance to Wellington Harbour.* One group of these mines, reported to contain a total charge of about 8,000 lb. of high explosive, was situated about 275 yd. from, and almost due south of the Harbour Board's rear leading navigation light. Owing to the

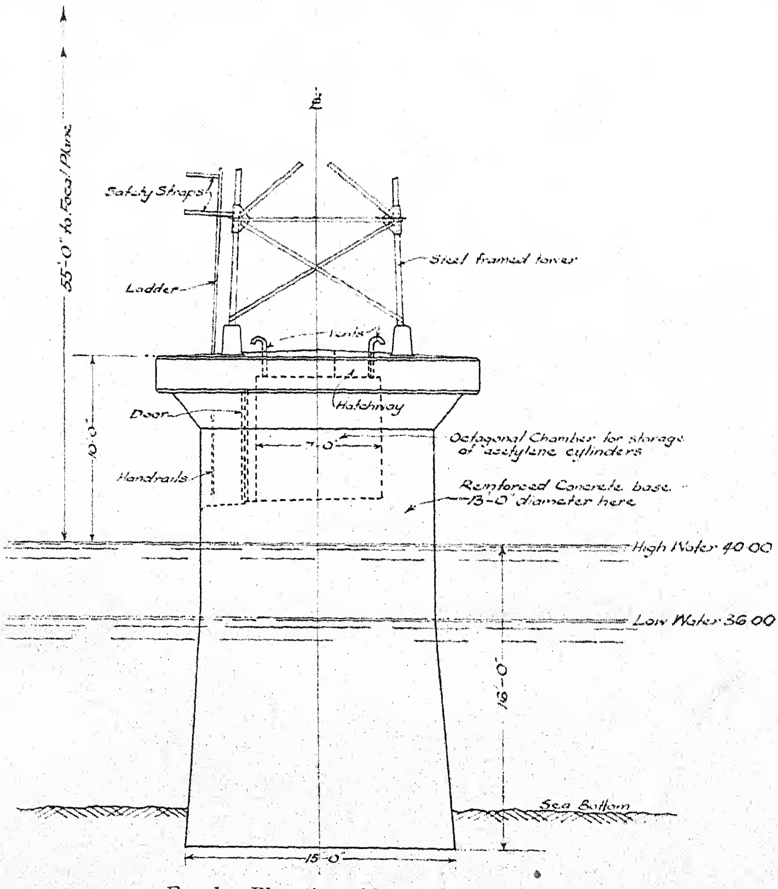


FIG. 1.—Elevation of base of rear leading light.

* Some aspects of this explosion have been discussed by W. M. Jones (1).

possible risk to the superstructure, the Board's engineers temporarily removed the steel tower supporting the light, thus leaving in place only the concrete pier, to the top of which the tower is normally attached. This pier has a diameter of 13 ft., and a total height of 26 ft., about 2 ft. of which is embedded in the harbour bottom. The pier is of reinforced concrete, solid in the low portion and hollow in the upper part, above high water level. In the chamber formed in this hollow are housed the bottles of gas for supply to the light above.

Some idea of the design of the pier may be gained from Fig. 1, for which I am indebted to the Chief Engineer to the Board. The centre of gravity of the pier is obviously below the level of the floor of the chamber, and probably near the level marked "low water" in the figure.

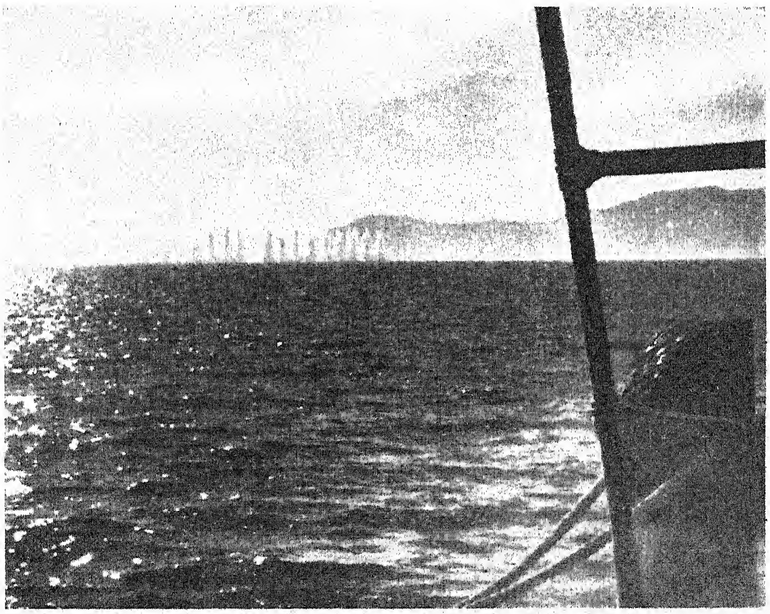


FIG. 2.—View of one of the mine explosions, July 13th, 1944.

With a view to estimating the magnitude of the shock suffered by the pier from the explosion, a horizontal pendulum was set up within the pier. As the project was arranged only a few days ahead of the time set down for the explosion, it was not possible to design and construct any elaborate accelerometer or timing device specially for the purpose. Accordingly the following very simple arrangements were employed. A gramophone motor with turntable was modified so that the latter rotated at about 38 R.P.M. On this table was mounted a circular sheet of plate glass, the surface of which was coated with carbon black by means of a smoky flame.

Two horizontal pendulums, of the Jaggar type (2) were mounted on the floor of the pier chamber. Their planes of vibration were in the N-S and the E-W directions respectively, thus being parallel and perpendicular to the line joining the pier to the site of the nearest mines.

In this way it was hoped to obtain a record of the two horizontal components of the shock. These two pendulums carried light needle points, which in their normal positions inscribed two concentric circular tracks on the rotating glass surface. No attempt was made to investigate the vertical component, as it was considered unlikely to be significant, and the apparatus needed to record it was not readily available.

Circumstances conspired to favour the experiment. The explosion of chief interest was the second of the series. A photograph of the event taken by Mr. W. R. B. Martin from a point about two miles south of the site, is reproduced in Fig. 2. The first explosion of the series was sufficiently far away not to affect the pendulums appreciably, but by means of a sensitive relay attached to a long vertical pendulum, the energy of this first explosion was made to release the trigger of the turntable. The disc was thus rotating at a constant and definite speed when the second shock arrived.

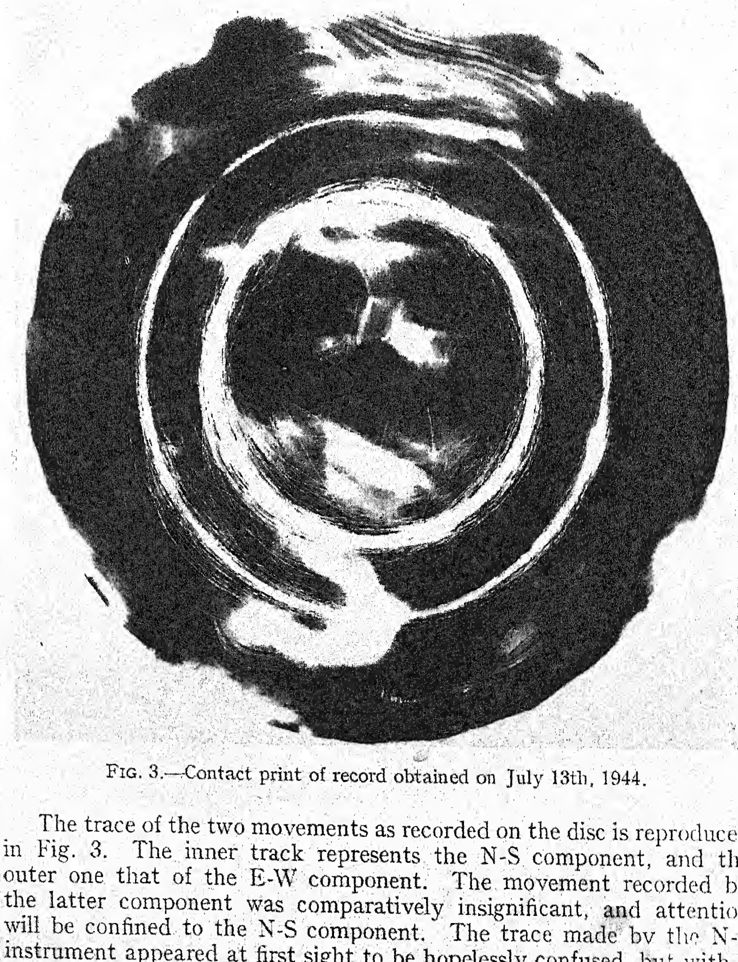


FIG. 3.—Contact print of record obtained on July 13th, 1944.

The trace of the two movements as recorded on the disc is reproduced in Fig. 3. The inner track represents the N-S component, and the outer one that of the E-W component. The movement recorded by the latter component was comparatively insignificant, and attention will be confined to the N-S component. The trace made by the N-S instrument appeared at first sight to be hopelessly confused, but with a

little perseverence in locating its intersections with the undisturbed circle, and measuring their angular distance apart, it was found possible to reconstruct the whole trace up to the tenth complete vibration.

A tracing of this is reproduced in Fig. 4. This chart resolves itself immediately into two parts :

(a) The initial movement, somewhat irregular in outline, consists of about four-fifths of a complete vibration.

(b) The subsequent movement takes on a much more regular and sinusorded form, with a considerably longer period.

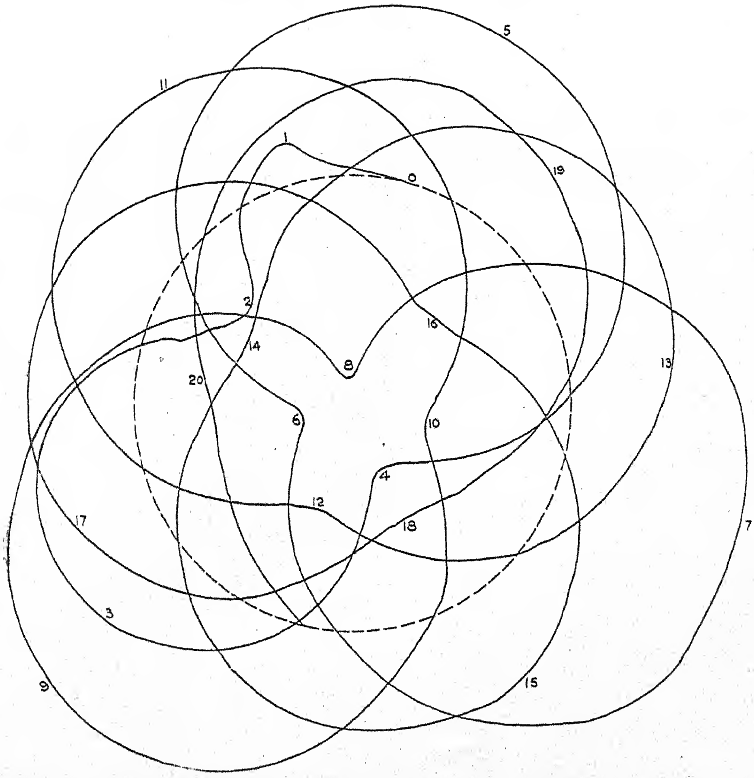


FIG. 4.—Tracing of portion of N-S component of seismogram.

The period of the turntable was about 1.60 sec., and the free period of the N-S component pendulum 1.11 sec. Measurements on the record indicate the period of the initial phase of the movement to have been about 0.28 sec. After the event, the equipment was removed to the laboratory and the horizontal pendulum set upon a simple shaking-table. This table was provided with an eccentric wheel of variable eccentricity, capable of imparting to the table approximately simple harmonic motion of pre-determined amplitude. The period of rotation of the wheel was maintained at about 0.28 sec., to conform to the period of the initial phase on the record. A number of records were thus obtained in succession on smoked discs, with applied amplitudes varying from 0.15 in. to 0.25 in. The amplitudes obtained on the records together with details of the original record, are set out in Table I.

TABLE I.

Lab. Record No.	Amplitude of S.H.M. (in.)	Amplitude on record (cm.)	
		1st.	2nd.
1.	0.15	1.0	1.8
2.	0.20	1.5	2.1
3.	0.25	1.8	2.9
Field record	—	1.4	3.1

From these data, the conclusion was drawn that the initial disturbance due to the explosion, regarded as a simple harmonic motion, of period 0.28 sec., had an amplitude of between .2 and .25 in., probably nearer the latter.

Now it is well known that the maximum acceleration in S.H.M. $= \left(\frac{2\pi}{\text{period}}\right)^2 \times$ maximum amplitude. On applying this formula to the above data, we conclude that the maximum acceleration experienced by the concrete pier at the level of the floor of the chamber lay between 25 per cent. and 31 per cent. of the acceleration due to gravity.

Further, the initial movement on the record was such as to indicate that the pier at this level moved, with reference to the heavy mass in the pendulum, *towards* the site of the explosion. The only reasonable explanation of this is that the movement of the pier consisted of a swing about its centre of gravity, the base moving initially northwards, and the top southwards. If this were so, the upper deck of the pier, to which the light tower is normally attached, must have experienced an acceleration appreciably in excess of the value arrived at above, and probably an acceleration in excess of $\frac{1}{2}$ g.

This conclusion is admittedly not of great accuracy, but it served to justify the removal of the tower. There can remain no doubt that it would have suffered considerable damage had it remained in place during the explosion.

GENERAL APPLICATION

The experiment also serves a more general purpose. At the present time, the designers of engineering and building structures to withstand earthquake shocks usually base their calculations on the assumption of a maximum horizontal acceleration of one-tenth of gravity. There is no adequate factual basis for this assumption, except the general one that many structures the design of which has been based on this assumption have survived moderate earthquake shocks. Much work done abroad suggests that such a simple mode of treatment is unsound and inadequate. In order to provide a more satisfactory basis for such calculations, it is desirable to obtain detailed and accurate information on the accelerations, periods and displacements occuring in actual severe earthquakes. This would require the location of a considerable number of strong motion seismographs throughout the area subject to severe earthquakes. At the present time, the only instruments available abroad which are considered suitable for this purpose are very expensive, both in first cost and also in maintenance charges. They are planned so as to give the desired data to a comparatively high degree of accuracy. They may be in a position to do this only once or twice a century. It is therefore contended that much less expensive, and collaterally less sensitive

instruments might be more suitable for the purpose. The results of the present experiment suggest that even such simple instruments as those employed here may be of inestimable value in fixing, with a reasonable degree of accuracy, the important points on which a more rational basis for earthquake design could be erected.

ACKNOWLEDGMENTS

I have to thank the Chief Engineer of the Wellington Harbour Board and the Director, Dominion Physical Laboratory, for providing facilities for carrying out this experiment, and for permission to publish this note.

REFERENCES

(1) JONES, W. M. (1946) : Note on Wood-Anderson Records of Mine Explosions at Wellington. *N.Z. J. Sci. and Tech.*, *28*, (*Sec. B*), 59-64.

(2) JAGGAR, T. A. (1929) : Amateur Seismology. *Scientific American*, *141*, 411-3.

A NEW LABORATORY MAGNETIC SEPARATOR FOR MINERAL SANDS

By V. C. OFFICER, Radio Development Laboratory, Department of Scientific and Industrial Research

(*Received for publication, 5th June, 1947*)

Summary

A new magnetic separator for laboratory use is described. A stream of sand falling through a magnetic field between triangular pole pieces is split up into several streams of particles having different mass susceptibilities, the dispersion taking place at right angles to the lines of force. If these streams are allowed to fall on an adhesive surface, a spectrum results. A system of slits can then be arranged to collect the desired fractions. The instrument can be calibrated so that mass susceptibilities are read off from the spectra. The smallest particles dealt with are those which just fail to pass a No. 200 B.S.S. sieve (aperture 0.0076 cm.), but improvements to enable much smaller particles to be separated are suggested.

PRINCIPLE AND THEORY

SAND falls in a thin stream from the hopper R in Fig. 1A, and passes between the triangular pole pieces of the electromagnet. The magnetic field is perpendicular to the plane of the paper and is approximately uniform over the triangular cross-section ABC. Outside this area the field falls rapidly, but not suddenly, to zero. A paramagnetic particle entering the field experiences a force urging it towards the stronger part of the field. Hence the path of the particle is deflected towards MN, the normal to AB, and similarly on leaving the field it is deflected

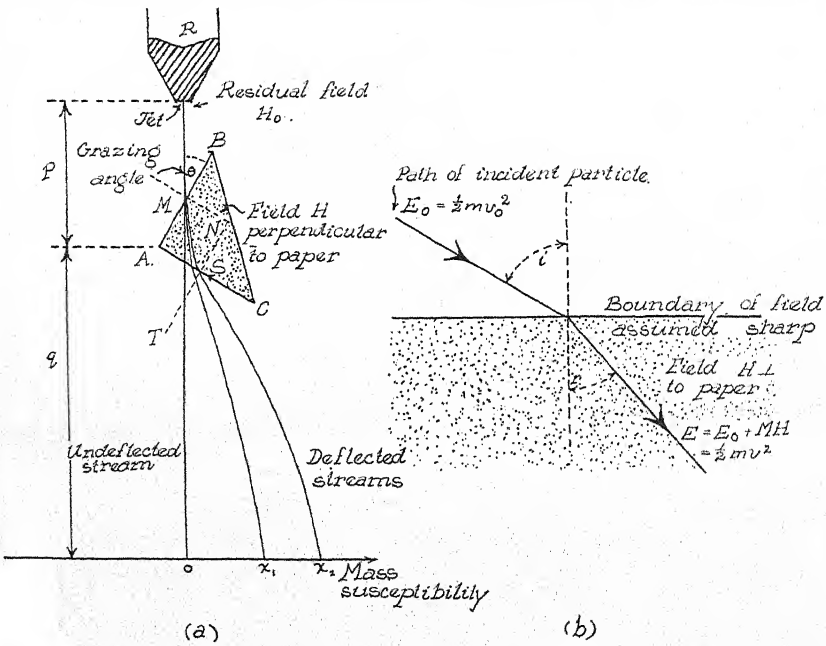


FIG. 1

away from the normal ST. Particles having different mass susceptibilities are deflected through different angles. The similarity of the action to that of a glass prism in dispersing a beam of white light can

be noticed. If the particles after having fallen a further distance strike an adhesive surface, they form a spectrum in which the various minerals in the mixture appear as lines (see Fig. 3).

The magnetic moment of a paramagnetic particle of volume V, mass m, and volume susceptibility κ, when placed in a magnetic field H, is given by :—

$$M = \kappa HV$$

$$= \frac{\kappa}{\rho} Hm, \text{ where } \rho = \text{density of particle.}$$

$$= \chi Hm, \text{ where } \chi = \text{mass susceptibility of particle.}$$

A quantity similar to a refractive index can be derived for the passage of a particle into the field.

In Fig. 1B, suppose the initial kinetic energy of the particle is :—

$E_0 = \frac{1}{2}mv_0^2$, where v_0 is its velocity on entering the field.

Then the kinetic energy of the particle after entering the field is :—

$E = E_0 + MH = \frac{1}{2}mv^2$, where MH is the magnetic potential energy lost on entering the field.

$$\therefore \frac{v^2}{v_0^2} = 1 + \frac{MH}{E_0} = 1 + \frac{2\chi H^2}{v_0^2}$$

But if the component of the velocity of the particle parallel to the boundary of the field is unaltered :—

$$v_0 \sin i = v \sin r$$

and the equivalent refractive index :—

$$\mu = \frac{\sin i}{\sin r} = \frac{v}{v_0}$$

$$\therefore \mu = \sqrt{1 + \frac{2\chi H^2}{v_0^2}}$$

which is a function of mass susceptibility, field strength, and particle velocity, but is independent of particle size, provided air resistance can be neglected.

If it is assumed that the particle is not acted on by deflecting forces after it enters the prism, and also that it is not accelerated appreciably by gravity while it passes through the prism, it should be possible to obtain μ from the usual optical formula for a glass prism set at minimum deviation :—

$$\mu = \frac{\sin\frac{1}{2}(A+D)}{\sin\frac{1}{2}A}, \text{ where } A = \text{refracting angle of prism and } D = \text{deviation of ray}$$

and deduce χ for the particle.

The phenomenon of minimum deviation does occur with the magnetic separator, but the effect of air resistance and the necessary approximations make quantitative comparison difficult.

CONSTRUCTION

The electromagnet operated from a 300-volt power supply and drew up to 300 m.a. The $1\frac{5}{8}$ in. diameter iron cores of the coils were screwed into the yoke, giving a ready adjustment of the air gap between the pole pieces. This air gap was usually about $\frac{7}{16}$ in. wide, but was varied from $\frac{1}{4}$ in. to $\frac{3}{4}$ in. Mild steel pole pieces of various shapes could be attached to the core faces. These pole pieces were of three types, (*a*), (*b*), and (*c*), shown in Fig. 2B.

Type (*a*) is a right-angled triangle, the right angle being used as the refracting angle. As is usually done with pole pieces, the edges are

bevelled off, but in this case it is advisable to make the cross-section curved to avoid sharp edges which would concentrate the field near them and collect particles with high susceptibilities. Type (*a*) is suitable for a narrow stream of particles issuing from a circular jet. The lower edge of type (*b*) is an arc of a circle of radius 5 in. This produces some focusing action by giving the particles that pass nearer to the apex of the prism a larger deflection on leaving the field than those passing farther away. Circular arcs form both the upper and lower edges of type (*c*), again producing a cylindrical lens effect. One of the focusing types is usually used.

The hopper can be made of brass, or iron if ferromagnetic materials are to be dealt with. The iron hopper shields the contents from stray

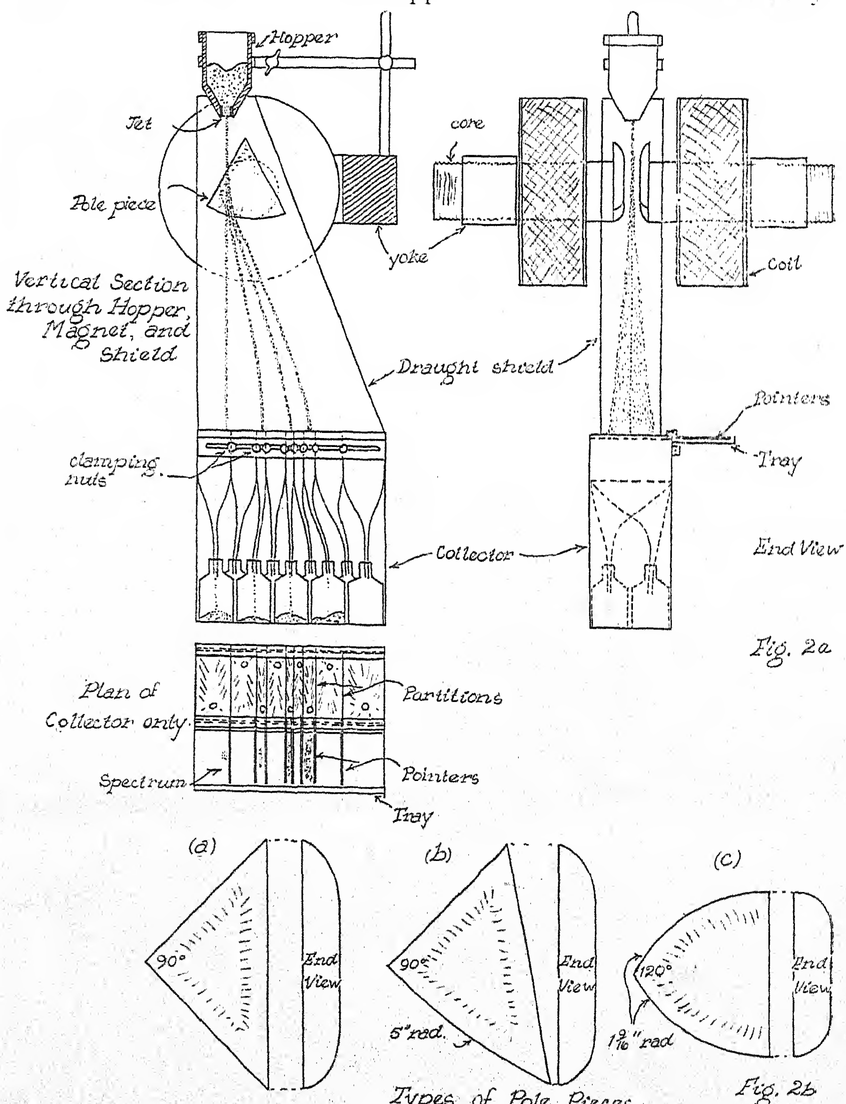


FIG. 2

fields, allowing the particles to run freely, but since the adjustment of the apparatus for separating ferromagnetic from non-ferromagnetic materials is so far removed from that for separating paramagnetic materials, it is more convenient to remove ferromagnetics from the material by hand.

The jet consists of a fine hole in a piece of thin copper or brass sheet attached to a brass ring and mounted as shown in Fig. 2A. The jet is removable, and different sizes ranging from $\frac{1}{32}$ in. to $\frac{3}{16}$ in. diameter may be used according to the grain size. A jet in the form of a slit $\frac{1}{4}$ in. long having a width of $\frac{1}{32}$ in. or greater could be used with focusing pole pieces. It was convenient to have this jet adjustable in width. The jet must be large enough to allow several particles to fall at once in order to form a steady stream. This steady stream must be protected from draughts throughout its fall by a brass draught shield.

The collector, which can be seen in Fig. 2A, consists of a box with eight sharp-edged vertical partitions connected by a bellows-like structure. The partitions can be slid along the box and clamped in suitable positions to collect the various fractions. Flexible tubes lead the fractions away to collecting-bottles. There is also a tray attached to the side of the box. Pointers attached to the partitions move over this tray, in which the spectrum of the material being separated can be placed, thus speeding the setting-up.

OPERATION

First the ferromagnetic minerals such as magnetite are removed from the material under test by using a small hand magnet. The material should be sieved, producing such fractions as (—120 + 200), (—60 + 120), and (—30 + 60), the numbers referring to B.S.S. sieves. The material runs better when the range of particle sizes is restricted and a jet of suitable size can be used for each sieve fraction. A spectrum of the material is made in the following manner. A strip of paper is coated with thick clear duco and placed in position on top of the partitions in the collector box. With a circular jet in use the stream of particles is set running, but is intercepted by a screen held between the jet and the prismatic field. The screen is withdrawn for a fraction of a second, and the particles which traversed the field will be found adhering to the paper, those with the same mass susceptibility arranged in lines across the paper. When this spectrum is placed in the tray on the side of the collecting box the partitions can be set so as to collect the desired fractions, and a larger quantity of the material run through.

If only a rough separation is required, it can be done more rapidly by using a slit jet and focusing pole pieces. The slit is arranged with its long side perpendicular to the field lines— *i.e.*, perpendicular to the analogous slit in an optical spectrometer. If the slit were placed parallel to the field, the edges of the stream would be too close to the pole pieces and the material would simply collect on them. As the more susceptible the material the higher the point at which it comes to a focus, the collecting-box should be placed in a sloping position, but for a rough separation a horizontal position will do if the field strength is suitably adjusted. Any particular fraction may then be purified by using a suitable circular jet.

It is necessary to adjust the air gap and the field strength so that the most magnetic material in the mixture does not collect on the pole pieces. If higher resolving power at the low end of the spectrum is required, that portion of the material must be treated again, using a larger field and a smaller air gap.

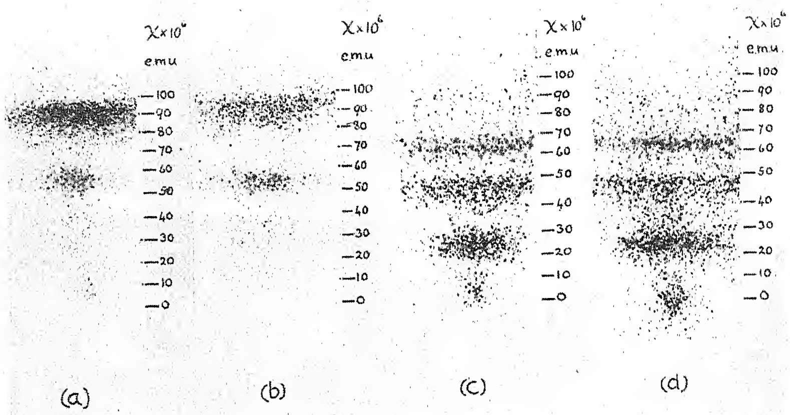


FIG. 3

RESULTS

The spectra in Fig. 3 illustrate several points. A scale of mass susceptibility can be inscribed along the spectrum if several minerals with known mass susceptibilities are passed through the apparatus and interpolation is carried out. This was done with several minerals whose mass susceptibilities had been determined using a Gouy balance. Spectrum (*a*), made with a (—120+200) sieve fraction, contains the smallest particles that can be separated readily in air. Spectrum (*b*) is the (—60 + 120) sieve fraction of the same sample, a gold-miner's concentrate from Bruce Bay. The main lines, ilmenite at 90 $\times$ 10^{-6} e.m.u., and garnet at 55 $\times$ 10^{-6} e.m.u., occur in both spectra. Spectrum (*c*) is a concentrate from a Stewart Island tin claim, showing a very faint line of ilmenite at 90 $\times$ 10^{-6}, garnet at 65 $\times$ 10^{-6}, wolfram at 47 $\times$ 10^{-6}, monazite at 24 $\times$ 10^{-6} e.m.u., and cassiterite, gahnite, and zircon near the undeflected position. There are two monazite lines, one at 24 $\times$ 10^{-6} e.m.u., and the other at 43 $\times$ 10^{-6} e.m.u. with the grains containing inclusions of a more magnetic material just distinguishable from the next line at 47 $\times$ 10^{-6} e.m.u. Spectra (*a*), (*b*), and (*c*) were made with the triangular pole pieces. Spectrum (*d*) was made with focusing pole pieces and the same sample as in (*c*). The lines are considerably narrower and the resolution of the lines at 43 $\times$ 10^{-6} and 47 $\times$ 10^{-6} e.m.u. is improved, but there is a considerable sprinkling of particles between the lines. This was caused by an unsteady stream of particles from a hopper that was almost empty.

All these spectra were made with a field strength of 6,800 oersteds, an air gap of $\frac{7}{16}$ in., and a circular jet. It will be noticed that the lines lengthen as the spectrum is traversed from the undeflected spot to the high susceptibility end, and in some cases they are slightly curved. This is caused by the particles which do not fall exactly midway between the pole pieces being attracted to one pole or the other along the lines of force, as well as undergoing their wanted deflection perpendicular to the lines of force. This attraction along the lines of force is often made the basis of magnetic separation, but the deflection usually depends

on the distance between the path of the particle and the pole piece. This would make the production of narrow lines with a finite beam width difficult. On the other hand, the deflection perpendicular to the lines of force does not depend markedly on the exact point at which the beam passes through the field.

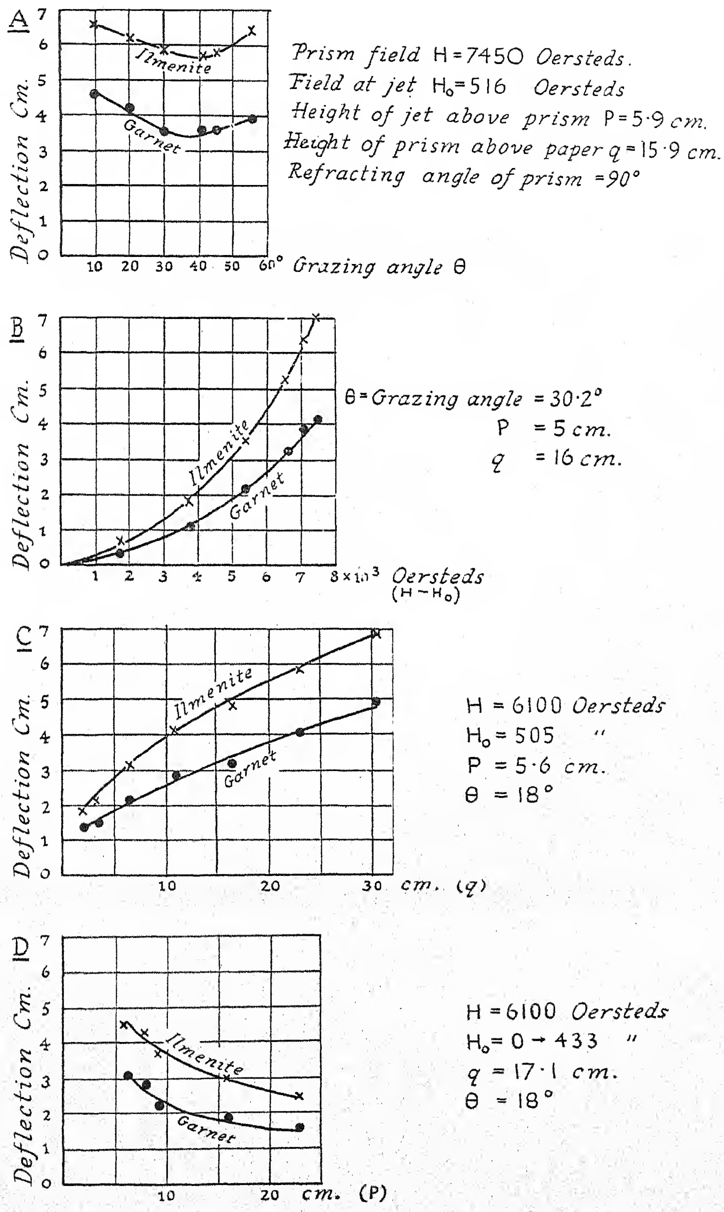


FIG. 4

Some quantitative tests were made to determine the way in which the deflection depends on the several variables.

Variation of Angle of Incidence: Minimum Deviation:—The complement of the angle of incidence, the grazing angle θ, was varied from 10° to 55° and a series of spectra made with a sample containing garnet and ilmenite. Fig. 4A shows that minimum deviation occurred for garnet at 36° and for ilmenite at 39°.

Variation of Field Strength:—Fig. 4A shows the way in which the deflection varies with increasing field strength. Tests with the Gouy balance showed that the mass susceptibility of ilmenite decreased appreciably with increasing field strength, whereas the value for garnet did not change. The dispersion would therefore have been greater at high fields if ilmenite had been truly paramagnetic.

Variation of Distance fallen by Particle after leaving the Prism (Fig. 4c):—These curves could be obtained from projectile theory if the air resistance to the particles was known. A convenient distance of fall at which adequate dispersion is obtained is found to be about 17 cm.

Variation of Distance fallen by Particle before entering the Prism (Fig. 4D):—The distance most used was 5 cm. to 6 cm.

SUGGESTED IMPROVEMENTS

Since the smallest particle size dealt with is that which just fails to pass a No. 200 B.S.S. sieve (aperture 0.0076 cm.), the usefulness of the instrument in geological work would be greatly increased if fine powders could be separated. This should be possible if the particles were allowed to fall in an evacuated chamber placed between the pole pieces. Only a rough vacuum would be required, and an ordinary water vacuum pump would probably be sufficient. As fine particles tend to stick together, a means of forming a thin, steady stream would be required. A jet in the form of a slit, adjustable in width and about $\frac{1}{32}$ in. in length, arranged with its length parallel to the field, should give very fine lines and good resolving power. Some form of mechanical tapping or agitating mechanism would be necessary to make the powder run through a very narrow slit. If the slit were only two or three particles wide, collisions between particles of different mass susceptibilities would not be frequent.

In the separation of large particles in air, collisions could be reduced by a preliminary transverse dispersion. This could be done by allowing the particles to fall through a field between rectangular pole pieces placed above the triangular ones, the horizontal components of both fields being parallel. This field would behave like a piece of plane glass in the case of light. If the falling particles entered the field obliquely they would be dispersed slightly in the direction of the field, but would still be falling vertically on leaving it, and different kinds of particles would be moving in different vertical planes. The deflection in the prism below, which takes place perpendicular to the field lines, could then be almost free from collisions. This would be valuable when a wide stream is being focused.

ACKNOWLEDGMENT

The author wishes to thank Dr. C. O. Hutton, who identified the minerals in Fig. 3.

SOME OBSERVATIONS ON SOLAR NOISE

By the Chief Engineer's Branch, General Post Office, Wellington

(*Received for publication, 9th May, 1947*)

Summary

This paper gives an account of some observations taken on solar noise during February, 1946. The observations were taken in the high-frequency spectrum, and correlate with the sun's azimuth. Frequencies are generally above the M.U.F.

INTRODUCTION

EARLY in February, 1946, during a period of high sunspot activity, operators at the Post Office radio station at Awarua took the initiative to determine azimuthal bearings on radio noise which was proving troublesome at the time. This paper, therefore, is made possible by the collective efforts of the Superintendent and operating staff at Awarua Radio in observing phenomena and the efforts of staff of the Chief Engineer's Radio Section in preparing the data for publication.

GENERAL

The radio noise exhibited a surging characteristic of a random nature, varying in duration from immeasurable periods to surges of duration of approximately one minute, and reaching high signal intensities. It was observed on a wide range of frequencies (6.7 Mc/s to 25.6 Mc/s), and was noticed to vary in intensity with frequency. It was possible to select a frequency for maximum value of noise, but data on these maximum values was not assembled.

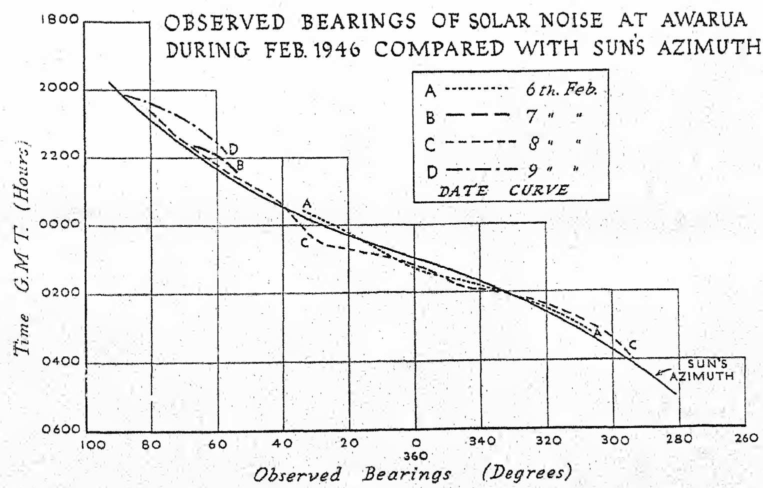


FIG. 1

(Date for graph D above should read 10th Feb., not 9th as shown)

Using a standard type DFG 24/2 Marconi Adcock direction-finder, bearings of good classification were obtained for periods during the 6th, 7th, 8th, and 10th February. The results correlate closely with the sun's azimuth as calculated by the Carter Observatory, Wellington (See Fig. 1), and leave no doubt as to the solar origin of the disturbing radiations. The deviations indicated of up to $\pm$ 10° from true bearings may be ascribed as being due to a combination of deviation in a somewhat disturbed ionosphere, together with normal bearing error.

A comparison was made between the frequencies and times of day at which noise was received and predicted conditions in the ionosphere. Assuming the layers of the ionosphere to be symmetrical in nature, one could, in general, expect radiation from the sun to reach the earth when possessing frequencies greater than the predicted maximum usable frequency (M.U.F.) for paths incident on the ionosphere at the specific angle.

Similarly, it would be expected that frequencies lower than the optimum working frequency (O.W.F.) would not be received. Calculations of such minimum expected frequencies were made on the assumption that the radiations were incident on the ionosphere at an angle equal to the sun's zenith angle and at a point distant h' tan θ miles from the receiver (h' = virtual height of ionosphere and θ = zenith angle). The errors introduced by this use of the flat earth theory are small except towards sunrise and sunset.

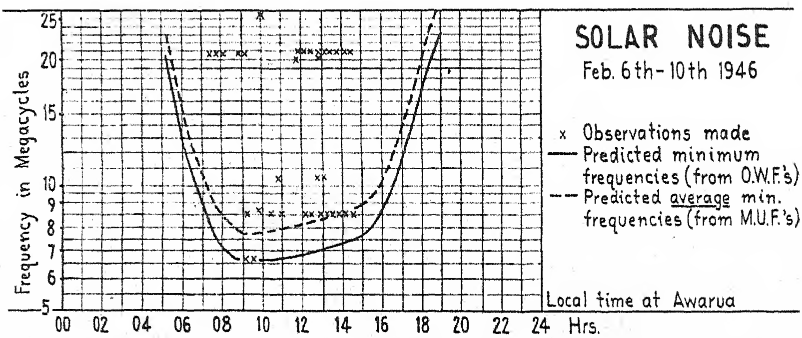


FIG. 2

It may be seen from Fig. 2 that all observations were made at times and frequencies on which reception could be expected on the basis of predicted conditions for the month. A few frequencies below the maximum usable frequency are not surprising as the observations were made during a period of high sunspot activity, when critical frequencies are often considerably reduced by magnetic storms.

CONCLUSION

Observations on solar noise have previously been carried out elsewhere, but most work has been in the U.H.F. spectrum. These results are particularly interesting for their references to such low frequencies and the conclusive nature of their correlation with the sun's azimuth.

The Radio Research Committee has indicated appreciation of the work performed at Awarua Radio and has requested the Post Office to take further observations should such noise reach similar magnitude at any future date.

NEW ZEALAND MICROSEISMS ASSOCIATED WITH THE STORM OF 14th - 16th FEBRUARY, 1947

By W. M. JONES, Dominion Observatory, Department of Scientific and Industrial Research, Wellington

(*Received for publication, 1st September, 1947*)

Summary

Microseisms associated with the storm of 14th-16th February, 1947, have been studied from the seismograph records at several New Zealand stations. Measurements were made of average trace-amplitudes, and of the periods of dominant wave-trains. Maximum amplitudes at Auckland, Wellington, and Christchurch were reached when the storm-centre was at sea, some 440 km. to the east of Wellington. The dominant periods ranged from 4 to 7 sec., except at New Plymouth (2 to 4 sec.), and tended to be greatest at the times of maximum amplitudes. Some associations of the microseismic activity with the strength and gust-frequency of southerly wind at Wellington are discussed.

INTRODUCTION

ASSOCIATIONS of certain types of microseisms with weather conditions, and the possibilities of using microseisms as an aid to forecasting, have been recognized for some time. Visser(1) mentioned their use during the first world war to give indications of the approach of remote depressions in the Atlantic. The recent development of the " tripartite " station by Ramirez(2), Krug(3), and Trommsdorf(4) has added greatly to the possibilities. In this, the direction from which the microseismic waves arrive is determined from the differences in times of arrival of individual waves at three pickups arranged a few miles apart at the apices of a triangle. The method was applied in the last war by the United States Navy in a research into the feasibility of tracking and forecasting the positions of hurricanes passing near Cuba and Florida. The results, according to Gilmore(5), " justify the belief that any type of meteorological disturbance can be *detected* within a range of 300 miles of a microseismic seismograph station, and that this distance increases up to 2,000 miles or more for major hurricanes or deep extra-tropical lows, especially when over water. The author believes also that with sufficient study and training an observer *can* distinguish between the formation and existence of a hurricane, a cold front, or an extra-tropical storm."

The mechanism by which microseisms are produced by atmospheric disturbances is not yet fully known. Among possible causes that have been considered are the effects of surf pounding on steep coasts, of strong winds striking mountain ranges, and the communication through water to ground of fluctuations of atmospheric pressure. It would seem that more than one mode of excitation may operate, and that a particular mode may dominate the microseisms commonly arriving at particular stations.

In New Zealand, many of our cyclones and other disturbances approach the country from the Tasman Sea, and cyclones also move down from tropical latitudes across the waters of the South Pacific. Direct observations of their tracks, whether from islands, ships, or aircraft, are often meagre, and the advantages to the forecaster, if reliable information could be obtained in good time by microseismic data, would be considerable. Less complete data might be useful in conjunction with other methods of long-distance detection, such as radar, microbarographic oscillations, or the development of sea-waves or swell.

No equipment especially designed for microseismic studies has been employed here. Although one or more of the tripartite stations would be the most likely method of getting definite data, the ordinary seismograph records can supply much material for general studies of local relations between microseismic activity and weather conditions, and for the consideration of possible modes of origin of microseismic waves. Little study of this material has been made so far. Baird and Banwell(6) found at Christchurch some association of the periods of microbarographic oscillations with those of microseisms on Galitzin records, and applied the methods of Lee(7) for obtaining general directions of arrival from phase-differences in the vertical and horizontal components. These methods depend on the waves being predominantly of the Rayleigh type, and the authors express some doubt on this point. The present paper will describe some features of the microseisms recorded on New Zealand seismographs during the passage of a more than usually violent storm. The variety of instruments concerned, with various periods and orientations, results in certain limitations, for example in comparison of the amplitudes at the different stations. For general studies of this type, difficulties that arise are (a) that the pressure-distribution over the region surrounding New Zealand is often complex, with perhaps more than one disturbance capable of producing a set of microseisms, and (b) that the meteorological data, for disturbances centred well out to sea, are often insufficient as a basis for establishing correlations between microseisms and the direction, distance, or intensity of disturbance.

INSTRUMENTAL MATERIAL AND METHODS OF MEASUREMENT

(A) INSTRUMENTS :

Records have been used from the following :—

Station	Type	Component	Period
Wellington	Galitzin	Z	Seismog, 4.8, Galvo. 10.6 sec.
	Milne-Shaw	N-S	10 sec.
	Wood-Anderson	N-S	0.8 sec.
Christchurch	Galitzin	NE-SW	24 sec. (Seismog. and Galvo.)
	,,	NW-SE	,, ,,
	,,	Z	13 sec. ,,
Auckland	Milne-Shaw	N-S	10 sec.
Tuai	Wood-Anderson	N-S	0.45 sec.
New Plymouth	Wood-Anderson	E-W	0.50 sec.
Kaimata	Wood-Anderson	NE-SW	0.71 sec.

As most of the microseismic periods to which attention has been given are from 3 to 7 seconds, the responses of the instruments are of course widely different. The short period Wood-Andersons are naturally unsuitable for such studies, but occasionally the amplitudes are sufficient for measurements of periods and estimations of the times of maximum activity. For the longer period instruments, the variation of magnification with period should not be very much, over this range of 3 to 7 seconds.

(B) AMPLITUDES :

For an estimate of general activity, the average trace-amplitude over a period of 5 minutes (3 for the Christchurch Galitzins) was measured by drawing a line through successive crests, and successive troughs, and measuring by planimeter the area so enclosed. A correction was subtracted for the width of the undisturbed trace. By doing this at suitable intervals, of 6 hours usually, but more often if desirable, a reasonably uniform progression was usually obtainable. For a given instrument, the method gives a good idea of the variations of general microseismic activity in the component recorded, if the variety of period is not so great as to introduce significant complications from varying magnifications for different periods. As between different instruments, the areas measured are of course not directly comparable, but changes in the ratio of amplitudes between components at the same place can be measured.

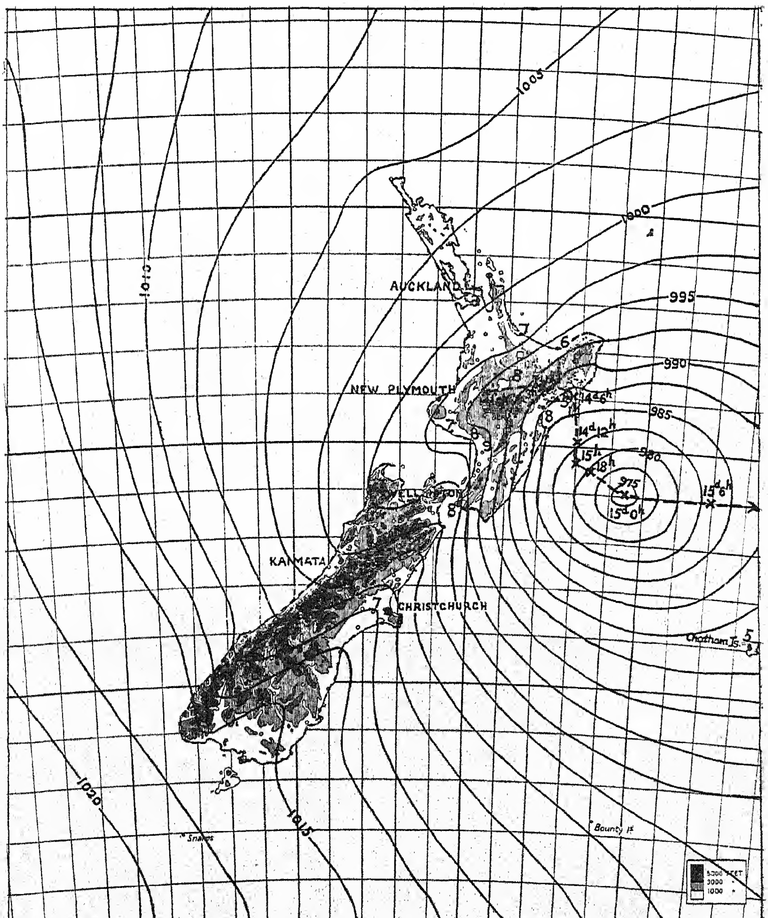


FIG. 1.—Synoptic chart for 15th February, 1947, 15d. 0h. Also shown are the local Beaufort wind-strengths, and positions of the storm-centre from 14d. 0h. to 15d. 10h.

(C) PERIODS :

For measurements of periods, the most prominent wave-trains were selected, if the motion showed reasonable uniformity for several successive waves, and an average period determined for the train. Usually the best train near the half-hour mark was measured at each half-hour. An alternative method, averaging the periods of about ten trains during an hour, at intervals of 3 or 6 hours, was found to give much the same general run of periods, and the standard deviation from the average

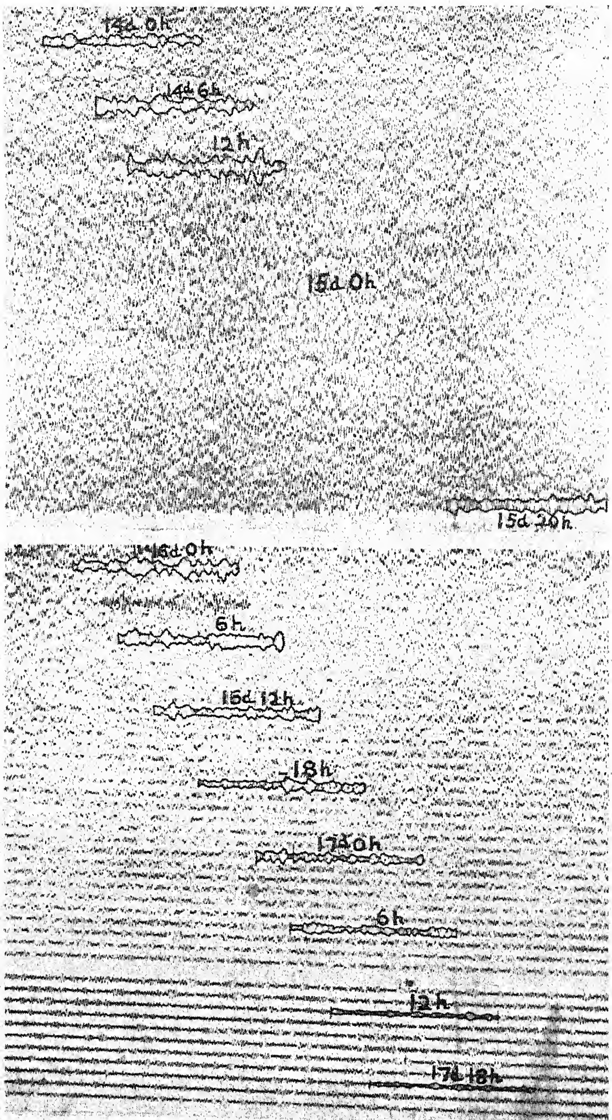


FIG. 2.—Portion of Galitzin Z record at Wellington, showing the rise and decrease of microseismic activity.

for the ten trains was usually less than ¼ sec. The individual readings by the first method are shown on the diagrams to exhibit the degree of scatter. Occasionally, when the motions were very irregular, no dominant regular wave-trains could be selected over a half-hour run; but for the most part, it is considered that a fair picture of the dominant periods was obtained.

THE STORM OF 14TH-16TH FEBRUARY, 1947

A fairly simple situation was afforded by the storm of 14th-16th February, 1947, which was violent over most of the North Island. The cyclonic centre developed inland after fairly quiet conditions, and then moved eastwards out to sea. The position of the centre and the pressure-distribution were thus known with some accuracy at the start, but less accurately as the storm moved off the land. Fig. 1 shows the synoptic chart as prepared by the Weather Office for 15th February, 0h. G.M.T., and also the path of the centre from 14d. 0h. to 15d. 10h. ca. The figures at stations give Beaufort wind-strengths at 15d. 0h. Pressures at the centre are shown in Fig. 3C, indicating the intensification of the cyclone up to a maximum about 15d. 0h. It may be remarked that the

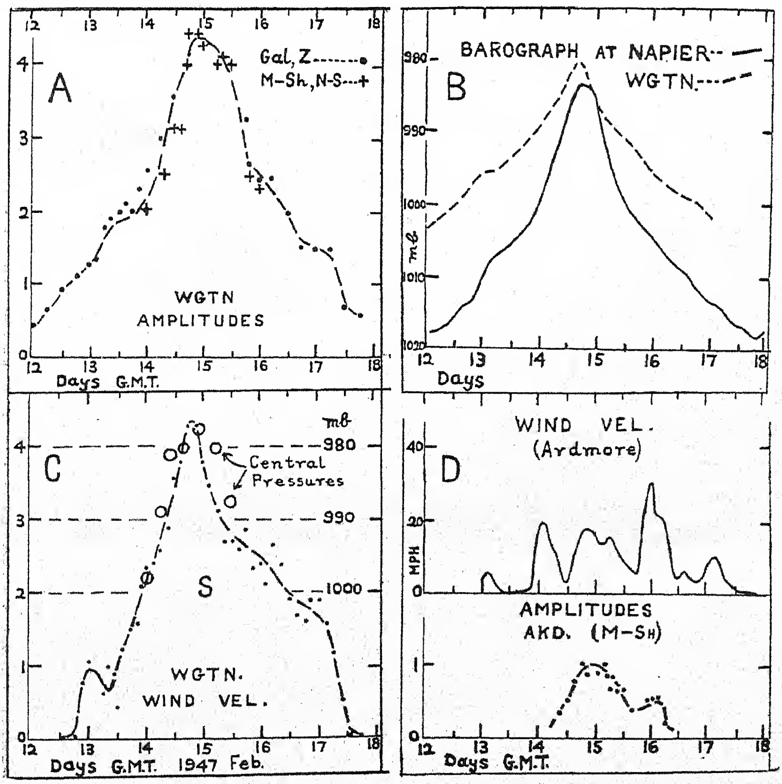


FIG. 3.—Average amplitudes at Wellington (A), and at Auckland (D); wind-velocities at Wellington (C) and at Ardmore, near Auckland (D); Barograms at Wellington and Napier (B); and pressures at the storm-centre (circles in C).

intensity and extent of this disturbance are much the same as those of a hurricane at Florida quoted by Gutenberg(8), p. 116, as an example of the efficiency of a tripartite station in indicating the direction of a hurricane-centre; they are however exceptional for New Zealand.

Variations of average microseismic amplitudes.

The progression of average amplitudes, as defined above, is shown for Wellington in Fig. 3A. (A reproduction of part of the Galitzin record at Wellington is given in Fig. 2). Towards the maximum the Galitzin traces were too much intermingled to be measured, while at minimum the Milne-Shaw amplitudes were too small, so that the values for the two instruments have been made to coincide at intermediate points by applying a suitable factor. The unit for average amplitude is of course arbitrary. A rise to and decline from a sharp maximum at 15d. 0h. is well indicated. The wind-velocities at Wellington, as recorded by Dynes anemometer, are shown in Fig. 3C, the maximum gust being 72 m.p.h. The circles in the same figure show the pressures at the centre, as far as they could be estimated, while Fig. 3B shows barograms at Napier, which was close to the path of the centre, and at Wellington. It is seen that for this case the microseismic activity could be correlated quite well with either the strength of southerly wind at Wellington, or with the intensity of the pressure-low at the centre of the cyclone, or even with the pressure-variation at Wellington.

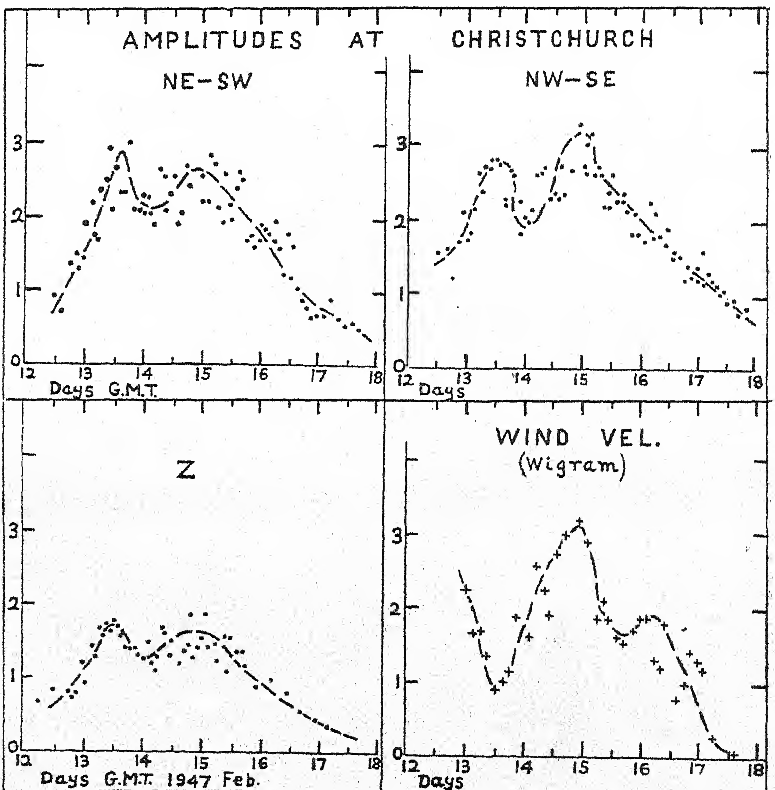


FIG. 4.—Amplitudes for three Galitzin components at Chrictshurch, with wind-velocities at Wigram.

At Christchurch, the amplitudes for the three Galitzin components are shown in Fig. 4, together with the wind record for Wigram, nearby. Although there is more scatter here in the values (the greater time-scale making an interval of 3 minutes all that could be conveniently covered by the planimeter), a fairly definite peak is seen for all three components at 15d. 0h. ca, again coinciding with a peak in the wind-velocity (maximum gust 50 m.p.h.). However a previous peak in amplitudes, at about 13d. 12h., was reached while the wind was low, before the development of the cyclonic centre. A cold front, weakening as it passed northwards, passed through Christchurch at 13d. 0h. and through Wellington at 13d. 12h. This perhaps was responsible for the microseismic activity of the first peak at Christchurch, and for a slight irregularity in the Wellington curve at 13d. 12h. The similarity of the amplitude-curves for the two horizontal components at Christchurch, the ratios of the two components being found not to vary in any systematic manner, is a point of interest. If the motion was purely longitudinal (horizontal component of Rayleigh or P waves) a change in the direction of a small originating centre would produce a change in this ratio. On the other hand, the change of direction in the present case of the storm-centre was not very much, and a larger originating area would tend to a more constant ratio. Again, if transverse components (from Love or S waves) were represented equally with longitudinal, the ratio would not be affected by a change of direction of any originating area.

At Auckland, Fig. 3D, a peak in amplitudes is again reached at 15d. 0h. ca, but little resemblance is apparent to the wind-velocities curve from Ardmore, some 15 miles away ; the wind-strengths here were smaller than farther south.

At New Plymouth, to judge only from a general inspection of the W-A record, the maximum was at about 14d. 6-12h., with a lull at 15d. 1h. ca, and a rise to a smaller maximum at 15d. 20h. ca, with hardly perceptible movements at 16d. 12h.

At Tuai, also W-A, perceptible microseisms began at 14d. 4h. ca, became most prominent from 14d. 18h. to 15d. 0h., and faded to very little at 15d. 20h.

At Kaimata, (inland from Greymouth), no activity was observable on the W-A record throughout the storm. In the last three cases, the absence of visible motion does not mean, of course, that none would have been recorded on longer-period instruments.

To sum up, maximum activity was observed at Christchurch, Wellington, and Auckland at about 15d. 0h., at Tuai a few hours earlier, and at New Plymouth some 15 hours earlier. At 15d. 0h., the cyclone was centered at 41° S, 179.5° E (see Fig. 1) over deep water, some 675 km. from Christchurch, 440 km. from Wellington, and 620 km. from Auckland. After 15d. 0h. a general decrease of amplitudes accompanied the increasing distances of the centre from all stations ; there may also have been a diminution in the intensity of the cyclone from the same time. Between 14d. 0h. and 15d. 0h., the distance of the centre from Christchurch did not vary very much, that from Wellington increased slightly, and that from Auckland increased considerably, so that over this period there is no apparent uniform relation between the increase to maximum amplitudes and the changes in distance from the centre.

The wind-velocity at a station would depend on its distance from the centre, and on the pressure-gradient in its vicinity, so that if the microseisms were originating from areas of strong wind or high gradient, a more or less circular zone would be involved, with an average radius of some 500 km. (the winds being strongest at about this distance from the centre, in the present case). There would however be complications if excitation of microseisms was favoured by the presence of deep water, or of cliffed shore-lines and surf, or of mountain-ranges, each of which has been postulated by different investigators, or again if conditions of transmission for surface waves were affected by structural features along their paths.

Periods.

The distribution of periods of the most prominent wave-trains is shown for Wellington in Fig. 5A. The range is from 4.4 sec. to 7.3 sec., with a well-defined maximum around 15d. 0h., the time of maximum amplitudes, and a perceptible drop in period after the passage of the weak cold front at 13d. 12h. ca. At Christchurch, Fig. 5B, apart from a rise of approximately ½ sec. about the time of passage of the cold front, there is little departure from a uniform range of 5 to 6 sec. At Auckland, Fig. 6A,

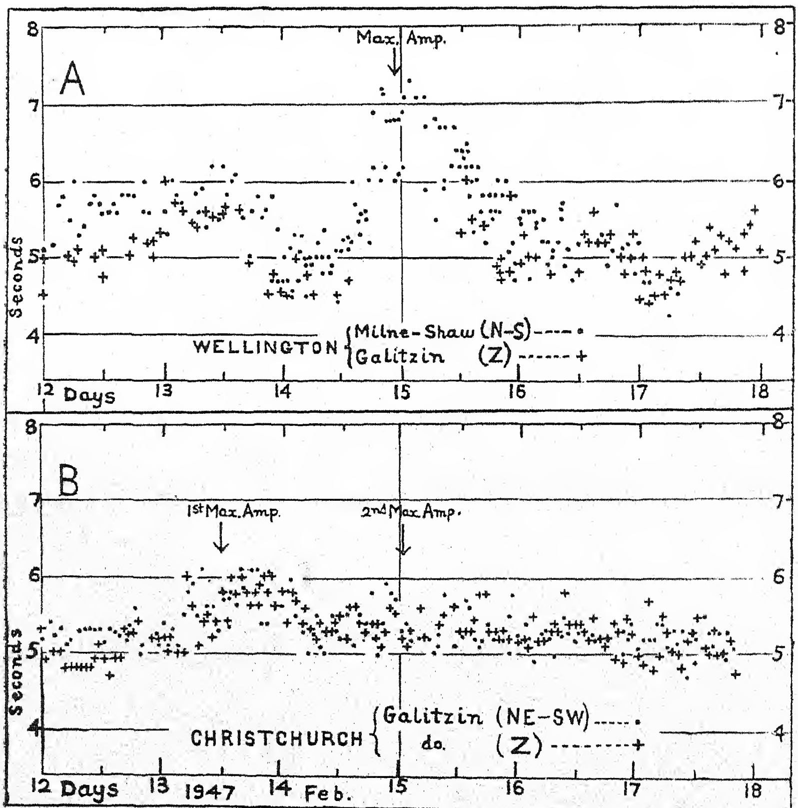


FIG. 5.—Periods of the most prominent and regular wave-trains, at Wellington (A), and Christchurch (B).

there is a rise from 5.5 to 7 sec. in approaching the maximum amplitudes, after which the periods remain between 6 and 7 sec. On the W-A records at New Plymouth and Tuai, the periods are measurable with less accuracy, owing to the low rounded shape of the wave-crests of the longer periods, and the prevalence of small shorter-period motions (1 sec. or so); but the Tuai periods can be seen (Fig. 6B) to range from 4 to 6 sec., with a rising tendency from 14d. 8h. to 15d. 12 h., while at New Plymouth (Fig. 6C), although a fairly well defined maximum appears around 14d. 12h. about the time of maximum amplitudes, the periods range only from 2 to 4.2 sec. The W-A periods are respectively 0.45 and 0.50 sec., so that there seems no instrumental reason for the difference. The New Plymouth instrument is very close to the surf-beaten coast of the Egmont Peninsula, and the explanation may lie in its being more susceptible to microseisms of such an origin than the other stations, or, as the microseisms would presumably originate during most of the period on the eastern side of the country, there might be obstacles to the passage of certain wave-periods across the grain of the North Island.

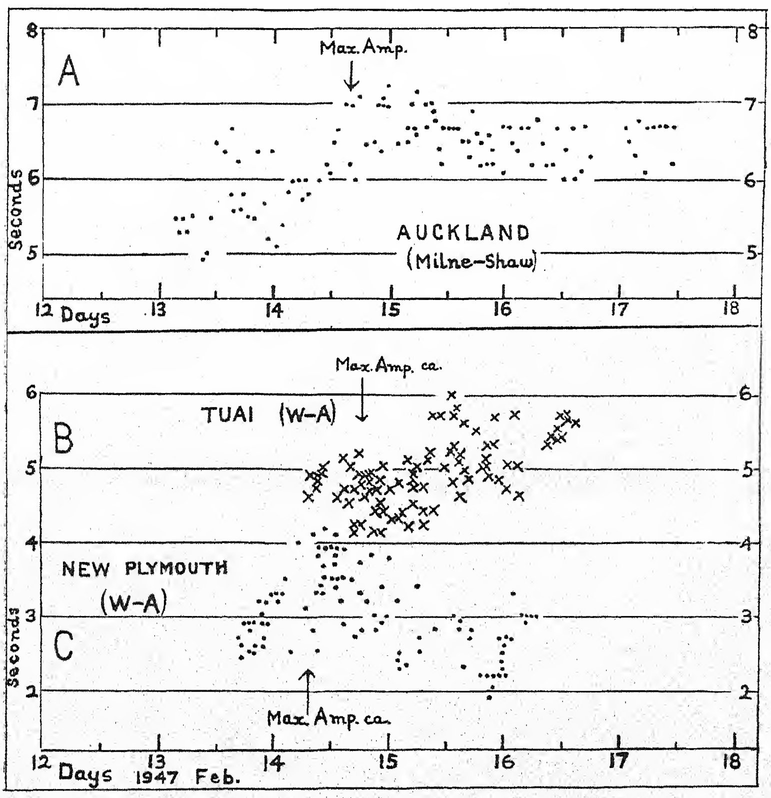


FIG. 6.—Periods of the most prominent and regular wave-trains, at Auckland (A), Tuai (B), and New Plymouth (C).

Within the range of distances involved, there appears to be no general tendency for the periods of the more prominent wave-trains to increase with distance from the centre of the storm. There is in this instance a tendency for the longest periods at a given station to occur at about the time of maximum amplitudes. This particular storm, however, if it is assumed that microseisms would originate over a considerable area, remained, during the time of observation, too close to the stations for the distances from stations to storm-centre to have much significance. The conditions would be very different, for example, from those of the recordings at St. Louis of microseisms originating in the Atlantic, or in Central Europe or Russia from origins on the coasts of Norway. We need therefore, especially from the point of view of forecasting possibilities, to study locally the effects from disturbances from greater distances. On our seismographs the recorded amplitudes from these will be smaller than those considered above, and instruments designed to respond to a range of say 4 to 7 sec. would be much better. The difficulty of finding conditions where only one disturbance is likely to be of influence will be intensified, as well as that of having accurate meteorological data. However, detailed descriptions of the courses of some intense cyclones are available from studies by the Weather Office; the microseisms associated with a few of these are being examined in a similar manner, and will be treated in a further paper.

Vibrations of Observatory buildings, or air currents, caused by strong winds have sometimes been considered as a possible source of some microseisms. To test this point at the Dominion Observatory, the Wood-Anderson record at the height of a later southerly storm was compared with a quickrun record from the Dynes anemometer at the Weather Office alongside. The strongest individual gusts were accompanied by a certain fuzziness on the W-A record, presumably representing vibrations of periods less than about $\frac{1}{3}$sec., which is the approximate limit of resolution on the records. Microseismic periods of the order of a second, which are common during the storms, do not appear to be directly associated with wind-gusts. It was noticeable, however, that the intervals between gusts were of the same order generally (not individually), from 4 to 7 sec., as those of the prominent microseisms. A certain general resemblance was noticed also between the succession of microseismic peaks, over a run of 7 or 8 min., and that of wind peaks, with the latter lagging some 9 sec. behind. Such a resemblance might occur if a proportion of the microseismic activity was due to the wind-gusts acting on either the sea, or on mountain-ranges, at a distance of the order of 25 km. Naturally at this distance the succession of wind-gusts would not be exactly the same as at Wellington, and a very close correspondence could not be expected. It is hoped to make further investigation of this point, for both northerly and southerly gales, as opportunity arises. As far as observations have gone, heavy microseismic activity at Wellington appears to be associated more regularly with southerly gales than with northerly gales of the same strength.

Attempts to identify individual wave-trains or amplitude-peaks at more than one station, especially Auckland, Wellington, and Christchurch were not successful. Nor was any consistent phase-difference observed between horizontal and vertical components on the Christchurch Galitzin records, nor, as mentioned above, any progression in the amplitude-ratios of the two horizontal components. It is hardly to be expected, however, that such phenomena would occur at the short ranges of distance involved in the present instance.

ACKNOWLEDGMENTS

The writer's thanks are expressed to Dr. M. A. F. Barnett, Director, and Officers of the Meteorological Office, and to Mr. H. F. Baird, Director, Magnetic Observatory, Christchurch, for the use of records and for other assistance.

REFERENCES

(1) VISSER, S. W. (1934) : On the Relation between Microseisms and Depressions in Western Europe and on the Ocean. *Proc. Kon. Akad. Wet. Amst.*, *37*, 738-46.

(2) RAMIREZ, E. (1940) : An Experimental Investigation of the Nature and Origin of Microseisms at St. Louis, Missouri. *Bull. Seis. Soc. Am.*, *30*, 35-84, 139-78.

(3) KRUG, H. D. (1937) : Ausbreitung der Natürlichen Bodenunruhe nach Aufzeichnungen mit Transportablen Horizontalseismographen. *Zeits. fur Geophysik*, *13*, 328-48.

(4) TROMMSDORF, F. (1939) : Untersuchen über die Natürliche Bodenunruhe mit Transportablen Dreikomponentenstationen. *Zeits. fur Geophysik*, *15*, 304-30.

(5) GILMORE, M. H. (1946) : Microseisms and Storms. *Bull. Seis. Soc. Am.*, *36*, 2, 89-119.

(6) BAIRD, H. F. and BANWELL, C. J. (1940) : Recording of Air-pressure Oscillations Associated with Microseisms at Christchurch. *N.Z. J. Sci. and Tech.*, *21*, 314B-29B.

(7) LEE, A. W. (1935) : On the Direction of Approach of Microseismic Waves. *Proc. Roy. Soc.*, *No. 866*, 149.

(8) GUTENBERG, B. (1946) : The Use of Microseisms in Hurricane Detection. *Trans. Am. Geoph. Union*, *27*, 111-7.

AN EXPERIMENTAL PRESSURE PLANT FOR TIMBER PRESERVATION RESEARCH

By K. M. HARROW, Wood Technologist, Plant Diseases Division, Department of Scientific and Industrial Research, Auckland

(*Received for publication, 24th July, 1947*)

INTRODUCTION

IN connection with investigations into methods of timber impregnation it was found necessary to install a pressure plant at the Plant Diseases Division. Requirements were the treatment of commercial size building timbers of sufficient length to obviate the effect of end penetration, operation over a wide range of initial and final pressures and temperatures, and a means of reading absorption rapidly and accurately. Drawings of experimental plants were obtained from overseas, but none was found suitable. In this paper is described a unit designed and installed at the Division in 1945.

DESCRIPTION OF PLANT

The unit (Fig. 1) consists of a treating cylinder(A) 12 ft. × 1 ft. a measuring cylinder(B) 5 ft. × 10 in., a 1¾ in. rotary pump(C), a dairy type vacuum pump(D), six 100 gallon storage tanks and pipes and fittings.

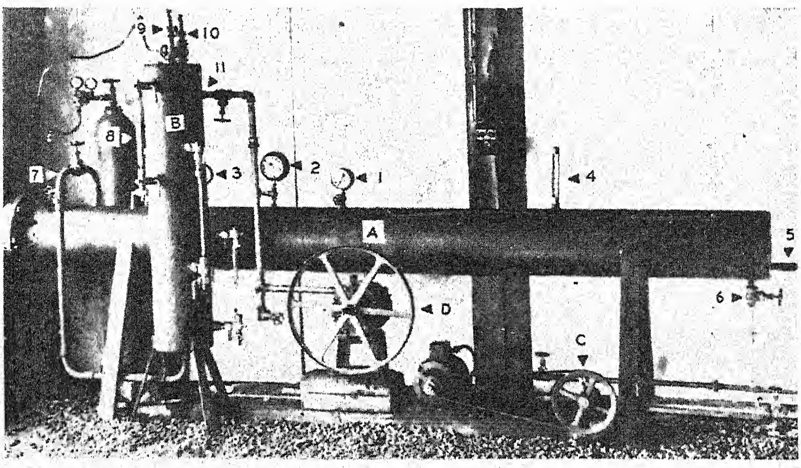


FIG. 1.—Experimental Pressure Plant.

The treating cylinder is set up with a fall of 1 in. from door end to facilitate emptying and to permit thorough displacement of air when filling. It is fitted with a vacuum(1) and two pressure guages 0-100(2), 0-500(3), thermometers(4), steam coil(5), inlet outlet valve(6) at the low end, and pipe(7) connecting the top of the door end to the base of the

measuring cylinder. The vertical measuring cylinder is fitted with three glass level gauges(8) arranged to give continuous readings over a range of 10 gallons. At the top is fitted a safety valve(9), with a compressed air intake attached to its base, an adjustable air bleeder valve(10) and a vacuum take off. The two cylinders have a solution capacity of 70 gallons and can be filled in 15 minutes. They can be evacuated in 4 minutes. Timber of dimensions up to 8 in. × 6 in. × 11 ft. may be treated.

CALIBRATION OF PLANT

With timber in the cylinder and the remaining space full of solution any drop in level in the measuring cylinder indicates a corresponding absorption into the timber, so that graduation of the vertical cylinder can be used to measure absorption. It was found that when known volumes of water were poured into this cylinder, a linear scale could be made. This has been graduated in 0.01 gallons and is suitable for solutions of any specific gravity.

PLANT OPERATION

The unit is capable of flexible operation. It can be filled with solution at any pressure between almost complete vacuum and 50 lb./sq. in. without any alteration in pressure during filling, and can operate to a maximum solution pressure of 400 lb./sq. in.

If treatments involving initial vacuum are required, the vacuum pump is set in operation and a bleeder valve in the vacuum line adjusted so that the desired pressure in the cylinder is obtained. The solution may then be drawn in from a storage tank through the inlet/outlet valve with the pump still running and the bleeder valve readjusted to maintain the required pressure. When the treating cylinder is full, solution comes over into the measuring cylinder which is filled until the liquid level is near the top of the glass level guages. The inlet and vacuum line valves are closed, the pump stopped and a start reading taken.

When initial air pressures are employed, air from bottles is introduced until the desired pressure is obtained, the solution is pumped in and the air release valve adjusted to bleed the displaced air, thus keeping the pressure steady. Again both cylinders are filled.

With the cylinder full, valves closed, and a start reading taken, pressure is applied to the solution by compressed air introduced from bottles through a gas regulator. This is adjusted to maintain the required solution pressure.

When the run is completed, the cylinders are emptied by reversing the rotary pump or by blowing out with compressed air.

PLANT ERROR

After the unit had been operated a few times it was found that an accurate balance between measured absorption and weight increase of wood could not be made. A check disclosed a plant error which is now allowed for in all readings. A correction is determined by filling the plant at different initial pressures in the absence of timber and applying increments of pressure to the solution. The drop in liquid level which results is probably due to contraction of small volumes of air trapped under the gauges, and to expansion of cylinders. Solution pressures above atmospheric are found to give a reasonably constant drop in level at any given pressure, irrespective of initial air pressure, provided the level at atmospheric pressure is taken as zero. However, when filled

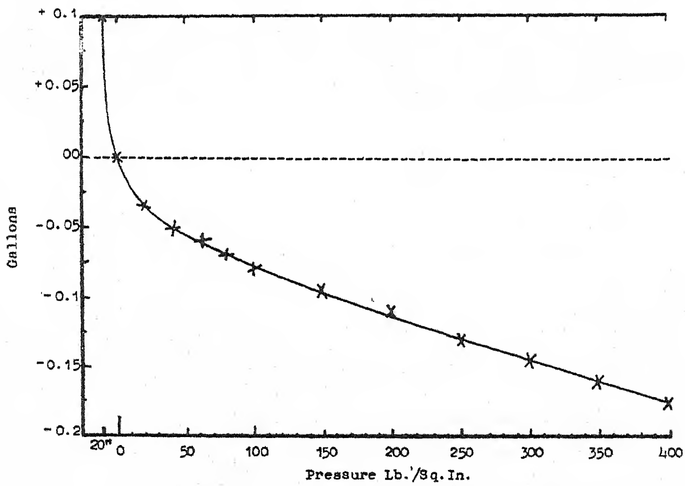


FIG. 2.—Correction Curve for Plant Error. **X** Shows Mean Value Determined at each Pressure.

under vacuum, the drop in level when the vacuum is released is not constant but varies with the conditions to which the solution has previously been subjected. The second of any two consecutive runs using initial vacuum shows a much smaller error than a vacuum run following a run using initial air pressure of say 20 lb./sq. in., which leads to the conclusion that the dissolved air affects this error considerably. A reasonably constant figure is obtained by recording the second of two runs filled under the same vacuum, so that a necessary preliminary to all runs requiring initial vacuum is to fill the plant under the vacuum, then pump the solution back, before the timber is introduced and the run commenced. Fig. 2 shows the correction curve which has been determined.

METHODS OF EVALUATING PRESSURE SYSTEMS FOR TIMBER PRESERVATIONS WITH AQUEOUS SOLUTIONS ABSORPTION

By K. M. HARROW, Wood Technologist, Plant Diseases Division, Department of Scientific and Industrial Research, Auckland

(*Received for publication, 24th July, 1947*)

Summary

New Zealand building timbers require preservative treatment to protect them from wood destroying beetles. The treating method used should ensure that cutting treated timber does not expose untreated susceptible wood, a requirement which can be achieved by using suitable pressure impregnating systems. Methods developed to compare gross absorption, kickback and nett retention produced by various pressure systems are presented.

INTRODUCTION

WHILE timber preservation in New Zealand is in an early stage of development, in Europe and America it has been employed since early in the 19th century to protect timber in contact with the ground from fungous attack. In the two latter countries, the principal destructive agents of building timber are fungi, which commonly attack the unpreserved ground floor timber of stone and brick houses. Damage by wood destroying beetles is seldom reported.

The hardwoods imported from Australia for poles and sleepers are sufficiently durable not to require preservative treatment, and buildings in this country are not normally attacked by fungi. When fungus attack does occur it is usually associated with faults in construction, such as absence of subfloor ventilation, building with timber to ground level, or with exterior timbers that have been opened up by insects.

However, in New Zealand where the majority of houses are wooden, wood destroying beetles have found a particularly suitable environment. Many early houses, were constructed of white pine, *Podocarpus dacrydiodes* A. Rich, a timber composed largely of sapwood which proved very susceptible to attack by the common borer, *Anobium punctatum* De Geer. Other building timbers however, such as kauri, *Agathis australis* Salisb., matai, *Podocarpus spicatus* R. Br. and rimu, *Dacrydium cupressinum* Sol. contain a large proportion of durable heartwood, so that even when the sapwood present is badly damaged, the structural strength of the building is seldom seriously impaired. While *Anobium* has caused the collapse of very few buildings since the use of white pine was discontinued, the damage to sapwood portions has brought about a considerable drop in commercial value of infested houses. To-day with restricted supplies of heart timbers, it is necessary to use a larger proportion of susceptible woods such as *Pinus radiata* Don and sap rimu. Present indications are that preservative treatment of such timbers is essential if future buildings are to have long life.

Other insects should also be considered. The native longhorn, *Ambeodontus tristis* Fabr., although not as widespread as *Anobium*, seriously damages even heartwood. With greater use of native hardwoods susceptible to *Lyctus* spp., this insect will also be a problem. These pests have made necessary preservative treatment of practically all building timbers. The problem is to find suitable means

Methods used elsewhere are cold dipping, hot and cold dipping, diffusion and pressure treatment. In New Zealand cold dipping has been in use commercially since 1938, while in 1947 a full scale pressure plant began operation.

There is a fundamental difference between the accepted requirements of preservative treatment elsewhere and in New Zealand. In countries where wood preservation has been developed primarily to protect ground line timber from fungi, a concentration of preservative in the outer portion of the timber is considered adequate. Provided timber is loaded with a specified amount of preservative, depth of penetration and distribution are considered to be of minor importance. Loadings of preservative suitable for ground line use have been determined by service tests over many years and have become more or less standardized in various countries. Choice of method is left to plant operator or purchaser.

In New Zealand, building timbers have to be preserved primarily against insects, and consequently thorough impregnation of susceptible wood is as important as is the use of sufficiently toxic chemicals. Already apparent is the tendency to accept preservative loadings and methods used for fungous control overseas, as suitable for insect control in New Zealand building timbers. This is obviously dangerous. Methods adopted in this country should ensure that subsequent cutting or checking does not expose untreated susceptible wood. As the method most likely to achieve this object, pressure treatment has been investigated first.

PRESSURE PROCESS

Two types of pressure process have been used :—

(1) The *full-cell* process, in which an initial vacuum is used to remove air from the wood and in which a high proportion of injected solution remains in the wood. This process is sometimes known as the Bethell process after John Bethell who patented it for tar oil treatments in 1838.

(2) The *empty-cell* process in which solutions are introduced into timber containing air at atmospheric pressure or above, and in which considerable proportion of the injected solution is forced out when pressure is released. There are two variants of the empty cell process :—

(*a*) The Lowry process, patented by C. B. Lowry in 1906, in which the solution is injected into the wood without a preliminary vacuum.

(*b*) The Reuping process patented in 1902 in which a solution is injected into wood containing compressed air.

Basically the processes used to-day are similar to those described above.

An investigation of these processes was undertaken in order to select combinations of initial and final pressures which would be satisfactory for treatment of New Zealand building timbers. Three factors must be considered when comparing treating systems ; absorption, distribution and time. In this paper are presented methods used to measure absorption.

ABSORPTION

For timber preservation purposes absorption is defined as the amount of solution taken up by or forced into the timber being treated. Two absorption figures are obtained with systems that result in some of the injected solution being forced out when the pressure is released. *Gross absorption* is the total amount of solution injected into the timber, while *nett absorption* or nett retention is the amount remaining after the imprisoned compressed air has ceased to force the solution out of the wood. This process of ejection is known as *kickback*.

(*a*) *Gross Absorption.*—Absorption is usually expressed in pounds of solution per cubic foot of wood. Comparative work with various pressure systems has shown that this method of measurement does not indicate the degree of saturation because of the variability in the specific gravity and moisture content of the timber.

Stamm and Hansen (1937) and Stamm (1938) have shown by measurement on several wood species that the specific gravity of wood substance in helium has an average value of 1.46, but when saturated with water the figure is 1.53. This apparent increase in specific gravity is due to a decrease in the volume occupied by the water adsorbed on to the wood substance. At fibre saturation point (30 per cent. M.C.) adsorbed water has a density of 1.113. To calculate the volume of voids at any point below fibre saturation the figure 1.46 should be used and a correction made for the density of adsorbed water at that moisture content. At fibre saturation and above, *i.e.*, when fully swollen, 1.53 is used. Any wood may be regarded as saturated immediately following pressure treatment with aqueous solutions.

Let Vf = Void volume of wood
Vw = Wet volume.
Wd = Oven dry weight.
1.53 = Specific gravity of wood substance saturated with water.

As the void volume of a stick is its volume minus the volume occupied by wood substance,

$$Vf = Vw - \frac{Wd}{1.53}$$

$$= Vw - 0.654\ Wd \qquad (1)$$

Table I demonstrates the effect of timber specific gravity on void volume. Data have been calculated using equation (1) for a series of hypothetical samples. The table shows also the percentage of void that would be occupied and the maximum gross absorption in lb./cu. ft. that could be obtained with the moisture content at 20 per cent.

TABLE I.—EFFECT OT TIMBER SPECIFIC GRAVITY ON VOID VOLUME.

Oven Dry Weight Units	Wet Volume Units	Void Volume Units	Per Cent. Void Volume Occupied at 20 Per Cent. Moisture Content	Max. Gross Absorption (lb./cu. ft.)
0.25	1.0	0.836	5.98	49.0
0.3	1.0	0.804	7.46	46.4
0.4	1.0	0.738	10.84	41.1
0.5	1.0	0.673	14.86	35.8
0.6	1.0	0.608	19.76	30.4

As specific gravities of the timbers treated during this investigation varied between 0.3 and 0.6 and moisture contents between 14 per cent. and 25 per cent. it is obvious that a method of gross absorption measurement which accounts for these variants had to be introduced.

It has been pointed out (Harrow, 1947) that in the experimental pressure plant, gross absorption is measured by volume and that densities of treating solutions are ignored since they do not affect volume. As the void volume of a stick determines the maximum volume of absorption possible above oven dry condition, void volume and maximum absorption have the same value. When a stick is treated the volume of injected solution plus initial moisture can be expressed as a percentage of void volume. This is termed *gross absorption*

percentage. In determining the volume occupied by initial moisture, its density is taken as 1.0, for as already pointed out the figure 1.53 for wood substance specific. gravity accounts for the increase in density of wood substance when saturated with water.

Set out below is a brief description of a typical empty cell treatment with the experimental pressure plant.

A 14 ft. length of 3 in. x 2 in. *P. radiata* has 2 ft. cut from each end and discarded. From each end of the shortened stick a 2 in. sample is cut off for moisture content determinaton. The remaining 10 ft. is weighed to the nearest ounce, placed in the treating cylinder and the door closed. Sufficient compressed air is introduced into the cylinder to give a pressure of 20 lb./sq. in. Pressure is held for 10 minutes, then the solution is pumped in, displacing air through a bleeder valve without varying pressure. When the solution has reached the required level in the measuring cylinder, the valves are closed and a start reading taken. Pressure is then increased to 40 lb. by additional compressed air, held until absorption ceases, and then further increased to 60 lb. In this way pressure is applied in increments up to 400 lb. When absorption is complete, pressure is released, the solution pumped out and the stick removed for weighing. The volume in gallons of the stick is then obtained from its length, and also its average width and breadth as determined from eight measurements per side. From air dry weight and moisture content of samples, the oven dry weight is calculated. Then using equation (1) its void volume in gallons is determined. The final reading at each pressure is corrected for plant error and added to the volume of initial moisture present. From these sums and the void volume, the gross absorption percentage at each solution pressure is calculated. Data from a typical empty cell treatment are shown in Table II.

When gross absorption percentage at each pressure is graphed against pressure, curves shown in Figs. 1, 2 and 3 are obtained. These are typical of *P. radiata* treated under the conditions given on the graphs. It will be shown in future papers that the curves are similar for permeable wood of the three species *P. radiata*, rimu and matai.

The method described measures degree of saturation and in doing so eliminates variations due to specific gravity and moisture content. Degree of saturation in so far as it indicates degree of penetration has value when selecting solution pressures suitable for preservative treatment of timber. A desired gross absorption percentage may be obtained by selecting any of a number of pairs of initial and final pressures. For example, Figs. 1, 2, 3 show that a gross absorption of 80 per cent. may be obtained by using any of the following three pairs of pressures: 20 in. Hg to 50 lb., atmospheric to 70 lb. or 20 lb. to 130 lb., and it can be assumed, other factors being equal, that the penetration obtained will be the same. However, because of kickback the nett retention resulting will differ considerably.

While this method of gross absorption measurement is unlikely to find use commercially, a knowledge of its implications is essential if sound preservation methods are to be used. It shows that specifying gross absorptions in lb./cu. ft. is unsound since there are large variations in specific gravity, moisture content and proportion of permeable wood both within a given charge and between any two charges. Speed of absorption into different sticks has also been found to vary considerably so that if a specified gross absorption is much less than the amount required for saturating the whole charge a number of sticks

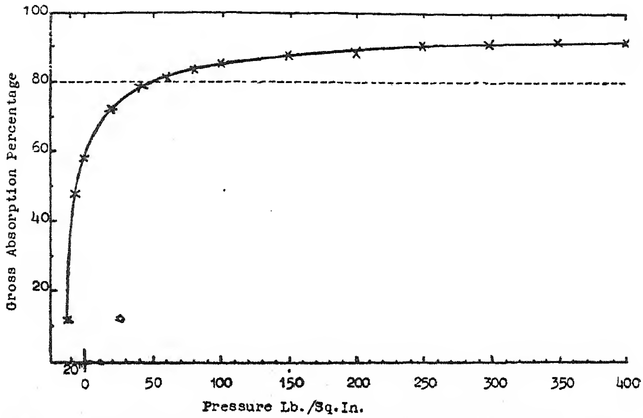


FIG. 1.—Gross absorption curve for the system 20 in. Hg. 400 lb./sq. in. with *P. radiata*. X's show the mean values determined with six runs.—Original.

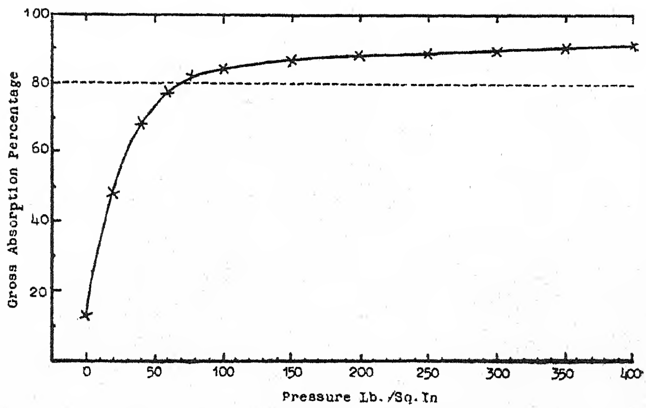


FIG. 2.—Curve for system. Atmospheric pressure 400 lb./sq. in.—Original.

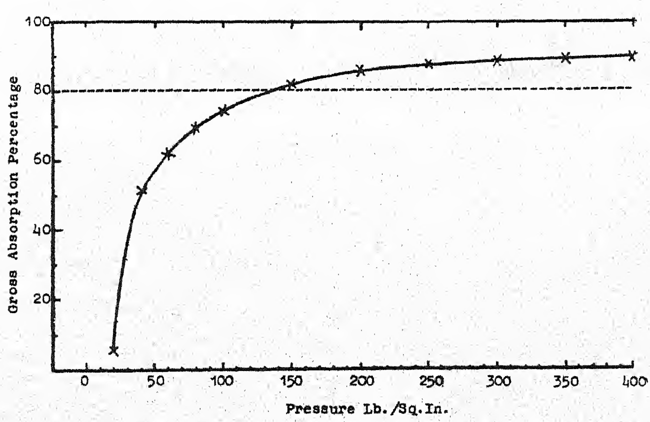


FIG. 3.—Curve for system 20 lb. — 400 lb./sq. in.—Original.

TABLE II.—CHARGE SHEET OF A TYPICAL RUN FOR GROSS ABSORPTION DETERMINATION. NETT ABSORPTION CALCULATION INCLUDED.

Run No. : 79. *Date* : 12.2.46. *Type* : Reuping. *Solution* : $ZnCl_2$.3 per cent.
Initial Pressure : 20 lb.
Final Pressure : 400 lb. *Solution.* : Sp.Gr. : 1.015

Stick No.	Dimensions (in.)	M.C. Per Cent	O.D. Weight (lb.)	Volume (Gal.)	Sp. Gr.	(1) Void Volume (gal.)
PR. 6	119x3.13x1.81	14.8	7.62	2.44	0.312	1.94
	Air Dry Weight (lb.)	(2) Wet Weight (lb.)	(5) Kick-back (lb.)	Nett Ab-sorption (lb.)	Nett Absorption Per Cent Dry Wood	Nett Absorption lb./cu.ft.
	8.75	13.31	12.00	4.56	60.0	11.7

READINGS

Pressure (lb./sq. in.)	Time (min.)	Reading (gal.)	(3) Corrected Readings	Amt. Absorbed (gal.)	(4) Total Liquid (gal.)	Per Cent. Total Voids Occupied
20	–	0.23	0.20	–	.11	5.7
40	115	1.13	1.09	0.89	1.00	51.5
60	90	1.36	1.30	1.10	1.21	62.4
80	43	1.50	1.44	1.24	1.35	69.6
100	30	1.61	1.54	1.34	1.45	74.7
150	30	1.76	1.68	1.48	1.59	81.9
200	23	1.85	1.75	1.55	1.66	85.5
250	22	1.90	1.79	1.59	1.70	87.6
300	7	1.94	1.81	1.61	1.72	88.7
350	5	1.97	1.82	1.62	1.73	89.2
400	3	1.99	1.83	1.63	1.74	89.8

(1) From equation (1).
(2) Weight after kickback complete.
(3) Reading corrected for plant error.
(4) Solution absorbed + initial moisture (A.D Wt.–O.D.Wt.).
(5) Gross absorption × Solution Sp.Gr.—(weight after kickback—A.D.Wt.)

would be poorly treated, while others would be saturated. To secure good preservation, pressures which produce high gross absorption percentages should be used and held until absorption ceases or as long as economically possible, thus ensuring that all the timber in a charge is adequately penetrated.

KICKBACK

All pressure systems used have resulted in solution being ejected from the timber on release of pressure. Kickback is rapid for the first hour or so, the process then continuing gradually for periods up to five days. In this investigation kickback has been expressed as a ratio of gross absorption, the latter being calculated from the volume measured and the solution density. The closer the ratio approaches unity the greater the kickback.

This important process results chiefly from expansion of air compressed in the wood during treatment. Air is either trapped in individual cells or forced ahead of the solution and compressed into an untreated core. Some is dissolved. As the pressure required to break

water films across the small orifices between cells is very much greater than that used in a pressure plant, it is assumed that kickback is produced by air trapped rather than that in an untreated core. It is therefore probable that air compressed in an untreated core will be dissipated by diffusion from cell to cell or remain in the wood until the water has evaporated and free exit is available. Bubbles of compressed air trapped in the penetrated wood can expand within each cell and force the solution out, but flow of air from cell to cell is unlikely. Bubbles which appear on the surface of timber after an empty cell treatment are probably produced by air coming out of solution. Bubbling does not occur over all the surface but is confined to areas of small checks. This hypothesis is supported by the fact that timber cut several days after an empty cell treatment still contains air under pressure which bubbles out from the centres of cut ends. Also a gross absorption percentage of 80 results in complete penetration of *P. radiata* but with the same figure a core of untreated wood remains in rimu and matai. This can be explained only by the presence of small unfilled spaces amounting to 20 per cent. of the void spread throughout *P. radiata* wood, while with matai and rimu the volume of unfilled spaces in the penetrated portion is much less. If kickback is produced by air in the penetrated portion, then *P. radiata* should have a greater kickback than matai and rimu under the same conditions. This is found to be true. Average kickback ratios for *P. radiata*, rimu and matai when treated with initial atmospheric pressure and a solution pressure of 80 lb. are 0.63, 0.37 and 0.29 respectively. As well as varying with timber species, kickback is greatly affected by initial air pressure. In Table III this is demonstrated by the mean figures of six runs with *P. radiata*. It will be noted that, while producing similar gross absorption percentages, treatments have resulted in very different nett absorptions and moisture contents after kickback.

TABLE III.—KICKBACK RATIOS, NETT RETENTIONS, AND MOISTURE CONTENTS OF *P. radiata* TREATED TO SIMILAR GROSS ABSORPTION PERCENTAGES BY THREE PRESSURE METHODS (MEANS OF SIX RUNS).

Initial Air Pressure	Final Solution Pressure (lb./sq. in.)	Gross Absorption Percentage	Kickback Ratio	Nett Absorption (lb./cu. ft.)	Moisture Content per cent. after kickback
20 in. Hg.	80	88.1	0.21	27.3	160
Atmospheric	150	86.8	0.63	13.0	72
10 lb./sq. in	200	86.2	0.76	8.3	50

NETT ABSORPTION.

In this investigation gross absorption data were obtained through increasing solution pressures by increments. Nett absorption on the other hand was determined with timber treated by immediate application of solution pressures known, from gross absorption studies, to produce high percentages. Selected pressures were held until absorption ceased. After removal from the treating cylinder, treated sticks were weighed, then held in a closed tank over water until weight was constant. If they were held in the open it was impossible to obtain reliable nett absorption figures by weighing because the effect of drying could not be accurately measured. The increase above air dry weight is the nett absorption. It is best expressed as the percentage salt in oven dry wood, w/w as this is the system used when determining toxicity of chemicals. It may be expressed as pounds of solution/cu. ft.

of wood if the defects of this system are recognized as shown earlier. To check the figures obtained by weighing, chemical analyses were obtained. Sticks were sampled by taking at each 10 in. a cross section ½ in. long. These were ground, bulked and sampled.

There are situations in which timber used should be treated to high nett absorptions as for example, marine piling treated with oil soluble materials. In building timbers, the lowest nett absorption that can be obtained after high gross absorption is desirable since the timber is then more easily dried and is light to handle after treatment.

Basic knowledge of absorption and the factors affecting it can be obtained by the methods described Before full use can be made of this information in pressure treatment, factors affecting distribution of salt and speed in absorption must be investigated. These will be discussed in future papers.

REFERENCES

STAMM, A. J. and HANSEN, L. A. (1937): *J. Phys. Chem.*, *41*, 1007.

——— (1938): *Ind. Eng. Chem.*, *41*, 1280.

HARROW, K. M. (1947): *N. Z. J. Sci. and Tech.*, *29* (*Sec. B*), 153-5.

JOURNAL OF SCIENCE
AND
TECHNOLOGY

Editor : D. Cairns, M.Sc. (Assistant Editor: M. O'Connor, M.Sc.) Department of Scientific and Industrial Research, Wellington

VOL. 29, SEC. B JANUARY, 1948 NUMBER 4

OBSERVATIONS ON THE OIL CONTENT OF NEW ZEALAND FRESH WATER EELS

By F. B. SHORLAND, Fats Research Laboratory, Department of Scientific and Industrial Research, and J. RUSSELL, Fisheries Research Laboratory, Marine Department, Wellington

(*Received for publication, 24th July, 1947*)

Summary

(1) Immature and mature eel populations from Lake Ellesmere and immature populations from Foxton Lakes, Manawatu River and Hutt River have been examined for oil content.

(2) The populations were found to consist of both *Anguilla australis* and *Anguilla dieffenbachii*, but in the area of the Manawatu River examined only one specimen of *A. australis* was obtained.

(3) Examination of the relationship between length and weight showed that over the size range 62-82 cm. the weight of *A. australis* could be calculated from the length using the equation $W = 33.94 (L - 48.5 \text{ cm.})$, $r = +0.975$, S.E.* of the estimate $\pm$ 80g. (where W = weight in grams, L = length in cm.) which applied generally to migrant and immature eels. In the case of *A. dieffenbachii* the equation $W = 38.45 (L - 43.51 \text{ cm.})$ $r = +0.995$, S.E. of the estimate $\pm$ 62g. was applicable to immature specimens over the size range 52-89 cm., but for migrant eels the size range of which varied between 104 and 137 cm. the relationship between weight and length was markedly different and conformed to the equation $W = 187.7 (L - 91 \text{ cm.})$, $r = 0.995$, S.E. of the estimate $\pm$ 613g.

(4) In the case of immature eels, the total oil content was found to vary from 7-23 per cent. for *A. australis*, while the oil content of *A. dieffenbachii* varied between 8-18 per cent. in the case of lake eels. Samples taken from the Manawatu and Hutt Rivers showed, in most cases, a higher oil content which varied from 8-23 per cent. In general, the oil content was found to increase with the length of the eel.

(5) Migrant eels, especially *A. dieffenbachii*, showed little change in oil content with length, the total oil content being approximately equivalent to that found for the largest size of immature eel.

(6) The relatively high concentrations of oil found in the tail portions of the larger immature eels, amounting to 23.5-29 per cent. in the case of *A. australis* and 20-37 per cent. in the case of *A. dieffenbachii* samples from the Manawatu River, suggests that these portions would form useful material to be treated separately for oil extraction.

(7) Immature eels may be distinguished from migrant eels by the different type of oil distribution. The ratio of oil content of the tail to the trunk was found, in the case of *A. australis*, to be 3.42 (S.E. $\pm$ 0.27) for immature eels as compared with 1.69 (S.E. $\pm$ 0.08) for migrant eels. Corresponding values for *A. dieffenbachii* were found to be 3.29 (S.E. $\pm$ 0.25) and 1.47 (S.E. $\pm$ 0.20) respectively. These values are markedly different from those calculated for *A. vulgaris* using published data, which showed that the oil in this species was almost uniformly distributed as between the trunk and tail portions.

* Standard error.

(8) Studies on the distribution of oil in the tissues of the immature eel showed that approximately 70 per cent. of all the oil present in the fish was concentrated in the tail, which comprised approximately 40 per cent. of the total weight of the fish. With the onset of migration, a remarkable change was shown to occur in the distribution of oil, resulting in the reduction of the oil content of the tail to 41 per cent. of the total oil reserves in *A. dieffenbachii* and to 57 per cent. of the total oil reserves in the case of *A. australis*. This relatively greater reduction in the case of *A. dieffenbachii* was accompanied by the production of large oil reserves in the ovaries, amounting to 20 per cent. of the total oil present in the eel.

(9) The implications of the present results in regard to eel canning and oil production are considered.

INTRODUCTION

FRESH water eels, because of their abundance, their high oil content and the presence of considerable amounts of vitamins A and D offer opportunities for production of oil as well as for utilization as food. Up to the present time, attempts to commercialize these fish for export have not been successful (1, 2) and their utilization has been restricted to the sale of small quantities in fresh or smoked condition (2) on the local markets, and to their use by the Maoris, who have long prized eels as a source of food. In response to a demand by U.N.R.R.A., eels were canned in various localities.

Interest in the control of eels as predators of trout has been shown by Acclimatization Societies, and in the principal eastern tributaries of the Oreti River in Southland, in the 1937-1938 season, systematic trapping showed the presence of 250-600 tons of eels per square mile of river water (1,3,4). Other observations (2) show that in 1942 the migrant eels alone from Lake Ellesmere amounted to not less than 550 tons in 100 square miles of shallow brackish water. Similar aggregations, probably not so large, occur each autumn in Lake Onoke, but some consider that the numerous lakes in the Waikato River system carry a total eel population that exceeds by far the available stock in any other district (2). The total weight of eels in New Zealand is thus sufficiently great to warrant a more careful survey.

It has been suggested than an annual catch of eels of up to 10,000 tons (5) is possible. This may be compared with the annual catch in New Zealand of less than 20,000 tons of all marine species. Though such a quantity of eels may be available, the biological evidence so far presented falls short of establishing the total quantities present or the amount of fishing which may be carried out without seriously depleting the existing stocks.

POTENTIAL PRODUCTION AND VALUE OF OIL FROM EELS

In the absence of accurate information concerning total quantities of fresh water eels in New Zealand, it is obviously impossible to assess the potential annual production of oil. The potentialities must be considerable, however, since the migrant eels from Lake Ellesmere alone are estimated to contain not less than 80 tons of oil as compared with the average local whale oil production of 300 to 600 tons. Tests have indicated that eel oil suitably prepared would not only be a substitute but would for some purposes, be preferable to whale oil (7). In view of its content of vitamins A and D, however, consideration should be given to its use as a veterinary oil. The New Zealand fish liver oil industry is based largely on shark liver oil, which, although

rich in vitamin A, is poor in vitamin D. Such oil, when fortified with synthetic vitamin D_2 or calciferol, is satisfactory for mammals, but cannot be used successfully with poultry, which require vitamin D_3*. In this particular connection, eel oil containing natural vitamin D could fulfil an important function, the value of such oil sold for veterinary purposes being somewhat greater than if sold as industrial oil.

Brief Description of the Two Species of New Zealand Eel

It is not proposed to deal in detail with the biological aspects of New Zealand eels in this paper, as the subject has recently been adequately covered by Cairns (3). In addition, Hobbs (6) is shortly communicating the results of observations made on Lake Ellesmere. However, for the purpose of clarifying subsequent discussion, it is necessary to point out that two species of eel are known to occur in New Zealand :— *Anguilla australis schmidtii* Phillips and *Anguilla dieffenbachii*, Gray, conveniently named short-finned and long-finned respectively, and differentiated by the relative lengths of their dorsal fins. The male of both species, in common with the behaviour of eels elsewhere, occurs only in the estuaries of large rivers and in the coastal lakes and lagoons. The long-finned female eel is found in all areas of permanent water to which access is possible ; the short-finned female eel is confined principally to the lower reaches of rivers, coastal lakes, and some inland lakes in the South Island. In the North Island, particularly in the Auckland Province, this eel inhabits some of the upstream waters in the same environment as the long-finned female (3).

In respect of weight, Cairns (3) records 0.9 to 1.1 kg. for the average adult† male and 1.8 to 2.7 kg. for the average adult female long-finned eel. Corresponding values for the short-finned species are respectively shown as 0.25 kg. and 1.1 to 1.4 kg. Hobbs (6), found the long-finned female migrant‡ eels from Lake Ellesmere in 1942 to range from 1.6 to 11.3 kg., (average 6.1 kg.), the male migrants varying from 0.25 to 0.96kg., (average 0.63 kg.). He also observed that the female short-finned migrants were typically 0.59 kg., specimens of over 1 kg. comprising less than 10 per cent. of the total numbers of this group. While the short-finned female is stated as seldom exceeding 1.8 kg., certain late maturing long-finned female eels have been found to weigh as much as 18 kg. (3). New Zealand eels are thought to spawn in deep water off the Great Barrier Reef, Australia (8). In the course of two years, the elvers or young eels, return to the river in the late spring and after maturing, which may take some fifteen years, they migrate in the autumn for spawning.

---

* Synthetic vitamin D_3 is now available commercially, and, although somewhat more expensive than the D_2, is being added by some firms to New Zealand fish liver oils used for poultry feeding.

† Term adult here indicates stage between first appearance of sex organ where it is possible to differentiate between male and female, and stage where gonads commence maturation.

‡ The migrant eel here represents the stage at which the sex organs have reached their maximum development in fresh water. (Private communication, D. Cairns.)

COMPOSITION OF EEL OIL.

Fresh water eels occur in various parts of the world (9), and consideration of the analytical constants obtained by various investigators shows that the composition of the body oil is variable.

TABLE I. CHARACTERISTICS OF EEL OILS

Species	Locality	Sap. Equiv.	Iod. Val.	Per Cent. Unsap.
A. rostrata (10)	North Atlantic coast of America	293.6	117.4	
A. vulgaris (11)	Europe	273.4	90.6–105.8	0.74
A. australis schmidtii (12)	New Zealand	289.2	107.0	1.0
A. japonica (13)	Japan (spring)	284.7	146.2	—
	(winter)	290.7	158.9	—
A. dieffenbachii (14)	New Zealand	290.4	122.5	0.80

The only detailed studies of the fatty acid composition of eel oil are those made by Shorland and McIntosh (14) on *A. dieffenbachii*, and by Lovern (15) on *A. vulgaris*, taken respectively from the Hutt River (near Upper Hutt) and from the estuarine waters of the River Dee in Scotland.

TABLE II. FATTY ACID COMPOSITION OF EEL OIL
(Fatty Acids Weight Per Cent.)

	Saturated			Unsaturated					
Species	C_{14}	C_{16}	C_{18}	C_{14}	C_{16}	C_{18}	C_{20}	C_{22}	Length
A. dieffenbachii (14)	2.0	14.9	0.8		19.7 (2.0H)	47.6 (2.6H)	14.4 (6.2H)	0.6 (?H)	130 cm. long (7 per cent. fat)
A. vulgaris (15)	4.3	16.8	2.5	0.1 (2.0H)	8.8 (2.2H)	39.4 (2.5H)	20.8 (5.6H)	7.3 (10.2H)	30-35 cm. (9 per cent. fat)
	4.3	17.8	1.7		9.2 (2.2H)	38.4 (2.7H)	20.1 (6.0H)	8.5 (9.3H)	50-55 cm. (24.1 per cent. fat)
Antarctic Whale Oil (16)	6.3	18.2	2.4	3.7 (2.0H)	13.3 (2.0H)	38.4 (2.6H)	11.4 (5.6H)	6.3 (9.0H)	

It is interesting that, although the iodine values of the oils from *A. dieffenbachii* and *A. vulgaris* reported in Table II were found to be similar (122.5 as compared with 118.5 and 119.0), their fatty acid compositions are shown to differ considerably. This difference is attributed by Lovern (17) to the fact that the *A. vulgaris* sample was taken from brackish estuarine waters and therefore resembles, in respect of its relatively high content of C_{20} and C_{22} unsaturated acids, a marine type of fat. The other sample was taken from an inland stream and therefore the fat is of the fresh water type, characterized by relatively decreased proportions of C_{20} and especially of C_{22} unsaturated acids and by increased proportions of C_{18} unsaturated acids. The latter, in common with the C_{18} unsaturated acids from oils of aquatic origin, were found to consist mainly of oleic acid together with minor proportions of stearidonic acid. Experiments made by Lovern (15) suggest that salinity has little, if any, effect on the composition of eel fat, the observed variations in fatty acid composition as between marine and fresh water fish

being probably of dietary origin. For example, eels (*A. vulgaris*), fed a diet rich in fat (herring with 20 per cent. fat) modified their depot fats, such ingested fat being incorporated in the depots with relative proportions of the various acids practically unchanged. The quantitative relationship between the amount ingested and the effect produced was, however, obscure.

The decreased proportions of highly unsaturated C_{20} and C_{22} acids found in the sample of oil from the Hutt River eel are of commercial interest because such oil would tend to resemble the non-drying edible vegetable oils and could no doubt be converted into a useful substitute even more readily than whale oil, the composition of which is shown in Table II for comparison.

In a further series of experiments Lovern (18) fed ethyl esters of fatty acids to eels. The diets produced certain modifications in the composition of eel body fats, but apart from a noteworthy increase in the content of palmitic acid, when ethyl palmitic was fed, the changes were too small to be differentiated with certainty from the combined experimental error and natural variation.

In the course of the various feeding experiments Lovern (18) noted that eels do not necessarily primarily utilize fat during partial starvation, but may use protein instead, thus actually having a higher fat percentage after loss of weight.

VITAMIN A AND D CONTENT OF EEL OIL

As early as 1927 the Medical Research Council of Great Britain (19) made reference to the fact that eel oil contains not only vitamin D but nearly as much vitamin A as good cod liver oil. In regard to New Zealand eels, Denz and Shorland (12) found in 1934 that a sample of eel body oil from Lake Wairarapa gave a vitamin A blue value of 4.3 units. Later measurements by Shorland and McIntosh (14) showed values varying from 4.3 to 12.0 or not less than 130 to 380 international units per gram, as compared with 1,000 I.U. per gram for medicinal cod liver oil. Cunningham (20) and Weeber (21) reported respectively a vitamin D content of 47 I.U. per gram and 25 I.U. per gram for the body oil of *A. australis*. Eel livers yield oils exceptionally rich in vitamin A, containing up to 100,000 I.U. per gram (cf. 14,22). Since, however, the livers comprise less than 2 per cent. by weight of the fish and have low oil content (14,22), their vitamin content has no commercial interest. Associated with the high vitamin A content of eel liver oil is the fact that Ward (23) has quoted a vitamin D content of 1,400 I.U. per gram as typical for the liver oil from *Anguilla* species.

Studies of *A. dieffenbachii* by Edisbury, Lovern and Morton (22) showed that the increase in oil content with weight (over the weight range 0.37-3.9 kg.) from 6.5 per cent. to 21.0 per cent. was accompanied by an increase in the total amount of vitamin A stored in the body compared with the amount stored in the liver. They found that the

oil was not uniformly distributed throughout the tissues, but that the highest proportions were present in the skin, the tail portion being less oily, followed by the still lower oil content of the trunk and head. In respect of vitamin A concentration, the oil from the trunk contained the highest proportions, with the tail next, followed by the head and skin oils. The body oils were found to range from 4-29 mg. per 100 g. with an average value of 12 mg. per 100 g., or approximately 300 I.U. of vitamin A per g.

Similar, though somewhat less extensive studies made on *A. vulgaris* by Edisbury, Lovern and Morton (22) showed that this eel, which matures at a much smaller size than *A. dieffenbachii*, had similar variations in respect to vitamin A potency to those exhibited by *A. dieffenbachii*.

EXPERIMENTAL

SAMPLING

In the case of the migrant eels, advantage was taken of the extensive collection made by Hobbs at Lake Ellesmere in March and April 1942, when he captured 540 long-finned eels, average weight 13.36 lb., and 3,420 short-finned eels, average weight 1.25 lb. From this collection, two cases comprising 222 short-finned eels and a further case containing 8 long-finned eels were selected for freezing (at 3-5°c.). The short-finned eels were divided into four size groups as follows :— 31 to 34 in., 27 to 30 in., 23 to 26 in., and 22 in. and under. From the smallest size group, 8 males were selected, the balance of 18 being rejected, some because they were females, and others because decomposition made determination of sex uncertain. The three groups of larger fish were all females. The largest fish (31-34 in.) were all well conditioned. From each of the other female groups 27-30 in. and 23-26 in., 5 attenuated specimens from a total of 52 were rejected. This rejection was deemed necessary for three reasons (6) :—

(1) To ensure reasonable uniformity of condition of female fish as between the fish.

(2) To ensure reasonable homogeneity within each group.

(3) Because the Ellesmere fish show a lower weight for length than is shown by samples from Lake Forsyth and Lake Onoke, and it is possible that the very attenuated specimens may be ones which had attempted unsuccessfully to migrate seawards the previous year.

After rejection of these selected fish, each of the female groups was reduced by fair sampling to 10 specimens.

In regard to the remaining collections of immature eels, the eels from Lake Ellesmere were frozen for transport and storage in Wellington, while those from other localities were received in fresh condition for sampling at the laboratory, and the selected material boxed for storage at low temperatures (3-5°c.). In sampling for oil extraction, the eels were divided into groups as shown in Table III, and an endeavour was made to have in each size group not more than 10, and not less than 5 specimens. If there were more than 10 fish within the size group, the numbers were reduced systematically. For example, if there were 15 eels in the size group 23-27 in., then two fish each representing as nearly as possible 23 in., 24 in., 25 in., 26 in. and 27 in. sizes were selected to give a uniform coverage over the whole size group.

TABLE III. FREQUENCY DISTRIBUTION OF SIZE GROUPS OF SAMPLES OF EELS USED IN THE PRESENT INVESTIGATIONS AND THE RELATIONSHIP BETWEEN WEIGHT AND SIZE GROUP

(a) Short-finned Eels.

Source	Locality	Date of catch	Size Groups: 22in. and under Av. wt. (g.)	22in. and under Per Cent. Total No.	23 in. - 26 in. Av. wt. (g.)	23 in. - 26 in. Per Cent. Total No.	27 in. - 30 in. Av. wt. (g.)	27 in. - 30 in. Per Cent. Total No.	31 in. - 34 in. Av. wt. (g.)	31 in. - 34 in. Per Cent. total No.	No. in sample
Immature Lake Ellesmere	Various parts except Taumatu	12/3/43—4/4/43	300 ± 22†	26.1	452 ± 31	24.6	806 ± 42	43.1	1038 ± 24	6.2	65
Lake Ellesmere	Lake Ellesmere and Selwyn River	23/2/44—7/3/44	306 ± 21	—*	519 ± 35	—*	918 ± 37	—*	1264 ± 77	—*	40
Foxton Lakes		–/4/43	275 ± 16	34.3	448 ± 17	38.8	824 ± 26	22.4	1128 ± 84	4.5	67
Hutt River system	Melling, Belmont, Waiwhetu	1/3/43—31/3/43	200 ± 28	50.0	529 ± 25	28.6	880 ± 59	21.4	—	—	28
*Migrants*** Lake Ellesmere	Taumatu	*Ca* 31/3/42	153	4.1	484	35.6	683	50.9	1228	9.4	222

† Standard error of the mean.

* Selected prior to despatch 10 in each group.

** The figures for the percentage distribution of the migrant eels are taken from Hobbs(6), while the weights refer to those actually found in the laboratory by the authors for the 38 eels used in the present investigation.

TABLE III.—*continued.*

(b) Long-finned Eels.

Source	Locality	Date of catch	Size Groups							
			22in. and under		23 in. - 27 in.		28 in. - 32 in.		33 in. - 37 in.	
			Av. wt. (g.)	Per Cent. Total No.	Av. wt. (g.)	Per Cent. Total No.	Av. wt. (g.)	Per Cent. Total No.	Av. wt. (g.)	Per Cent. Total No.
Immature Lake Ellesmere	Various parts except Taumatu	12/3/43—4/4/43	437	50.0	928	22.1	1470	16.7	3757	5.6†
Lake Ellesmere	Lake Ellesmere and Selwyn River	23/2/44—7/3/44	411±29	20.7	616±118	13.8	1360±60	17.2	1842	6.9
Foxton Lakes		–/4/43	315±25	25.0	623±40	53.6	825	3.6†	1630±96	10.7
Hutt River system	Melling, Belmont, Waiwhetu	1–31/3/43	390±13	30.4	737±40	50.0	1200±70	13.0	1896	4.4
Manawatu River system	Mangaone, Kahitarawa and Tiritea stream	–/3/43	320±42	5.6	740±52	27.8	1117±92	27.8	1804±481	22.2

† One eel only.

TABLE III.—*continued*.

(c) Long-finned Eels.

Source	Locality	Date of catch	Size Groups: 38 in. - 42 in. Av. wt. (g.)	38 in. - 42 in. Per Cent. Total No.	43 in. - 47 in. Av. wt. (g.)	43 in. - 47 in. Per Cent. Total No.	48 in. - 52 in. Av. wt. (g.)	48 in. - 52 in. Per Cent. Total No.	Total No. in sample
Maturing Lake Ellesmere	Various parts except Taumatu	12/3/43—4/4/43	4200	5.6†	—	—	—	—	18*
Lake Ellesmere	Lake Ellesmere and Selwyn River	23/2/44—7/3/44	3910 ± 328	20.7	—	—	6799 ± 294	20.7	29
Foxton Lakes		1/4/43	—	—	—	—	6680	7.1	28
Hutt River system	Melling, Belmont, Waiwhetu	1–31/3/43	2769	2.2†	—	—	—	—	46
Manawatu River system	Mangaone, Kahitarawa and Tiritea stream	30/3/43	2835	5.6	4319 ± 323	11.2	—	—	54

† One eel only.
* Individual weights not taken so that standard error cannot be calculated.

(d) Long-finned Eels.

Source	Size Groups: 39 in. - 42 in. Av. wt. (g.)	45 in. - 46 in. Av. wt. (g.)	49 in. - 51 in. Av. wt. (g.)	53 in. - 55 in. Av. wt. (g.)	Total No. in Sample
Migrating Lake Ellesmere (Taumatu) 31/3/42	2,576	4,500	6,120	9,070	8

The figures in Table III for the distribution of the size groups, (expressed as a percentage of the total, in the case of the Lake Ellesmere migrant short-finned eels), are based on Hobb's measurements covering 222 eels, while the average weights shown are those obtained on the smaller sample used for oil extraction. The average weight (153 g.) shown for the size 22 in. and under, appears low. This is because males only are included in the measurement. The average value found for male and female eels together was 317 g. As explained earlier, however, the female specimens were rejected. As no individual weighings of the migrant short-finned eels were made, the standard errors of the average weights are unknown; but assuming similar values of those found for the immature eels it would seem probable that the migrant eels from the 27-30 in. group are significantly lighter than the immature eels from the corresponding size groups.

In regard to the immature eels, the large proportion of small size eels from the Hutt River is perhaps not indicative of the general population as these samples were secured by spearing instead of by trapping. Considering the wide variations in locality, the variations in average weight within each size group (apart from 22in. and under) appear small, and with the exception of the heavier short-finned eels of the Hutt River in the size group 23-26 in., as compared with those from Foxton Lakes, the differences are not significant. The average weights within each size group of the long-finned eels are also shown not to vary significantly within the localities examined. No exact comparisons can be made between size groups of 22 in. and under, since these are made up of eels of differing lengths. The average lengths of this size group, however, may be given in inches as follows, the value for the short-finned eels being the first. Lake Ellesmere 1943, 19.6 ± 2.0*, 20.0 ± 2.4; Hutt River 19.0 ± 2.2, 21.0 ± 1.2; Foxton Lakes 21.3 ± 0.7; 21.5 ± 1.3; Manawatu River, (long-finned only) 21.0 ± 1.6. The distribution of size groups in Table III, shows that in the short-finned species there is no marked discrimination between mature and immature eels. In the case of the long-finned species the majority of the immature eels are shown to occur in the size groups below 39-55 in. which is characteristic of the size range of the migrant eels examined in this investigation.

The distribution of the two species shown in Table III accords with the description given by Cairns (3) and in this connection it may be noted that, with one exception, the eels of the Manawatu River system which were taken well inland, belonged to the long-finned species.

THE RELATIONSHIP BETWEEN LENGTH AND WEIGHT OF EELS

The weights of New Zealand eels at different lengths, based on general collections have already been given by Cairns (3). Comparisons between his values and the present are, in general agreement as are those supplied by Hobbs (6) for Lake Ellesmere. In the case of the long-finned migrants from Lake Ellesmere rough weighings of the total weight at Lake Ellesmere and subsequent weighings in the laboratory, after a period of six months cold storage showed a loss in weight of *ca.* 15 per cent. in accordance with the differences shown in Fig. 2, between Hobb's values and the present data. In regard to the short-finned migrant eels, where more adequate precautions were taken, no losses were observed between field and laboratory weighings, subsequent to cold storage.

* Standard deviation.

The material collected from Lake Ellesmere in 1943 was also frozen prior to transport to the laboratory for weighing. In all other cases the weights were determined on live eels.

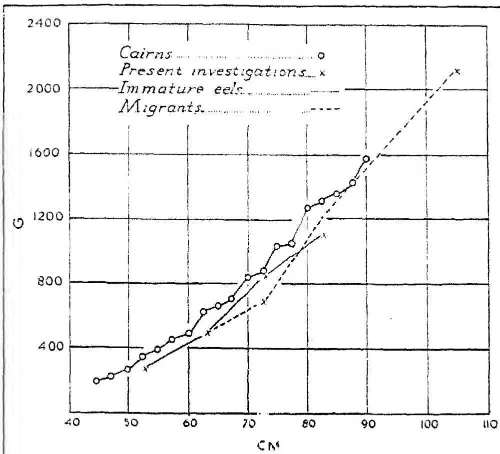


Fig 1 Relationship between length & weight of A. australis

M.T. 1947

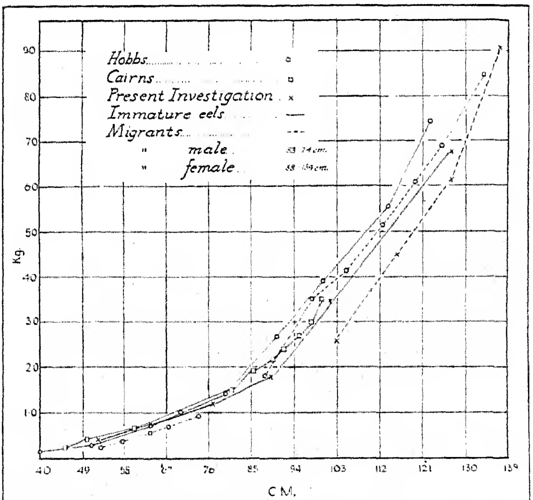


Fig. 2 Relationship between length & weight of A. dieffenbachii

The curves for short-finned eels show general similarity between migrant and immature samples, the weight-length relationship over the range 62-82 cm, being conveniently expressed by the equation $W = 33.94 (L - 48.5 \text{ cm.})$, $r = +0.975$, standard error of the estimate $\pm$ 80 g. Where W = weight in g. and L = length in cm. Application

of the above equation to the two largest eels from the Lake Ellesmere collection showed an error of -11.5 per cent. in the calculated as compared with the observed weight.

In the case of the long-finned eel, using the data obtained in the present investigation, two distinct relationships between length and weight are shown. Over the range 52-89 cm. the length-weight relationship may be expressed by the equation $W = 38.45\ (L - 43.51\ \text{cm.})$, $r = +0.995$, standard error of the estimate $= \pm\ 62$ g. Thereafter the weight increases relatively more rapidly than the length, conforming to the equation $W = 187.7\ (L - 91\ \text{cm.}^*)$, $r = 0.995$, standard error of the estimate $\pm\ 613$ g. The long-finned species is thus shown to be markedly different from the short-finned species both in regard to its greater weight per unit of length as noted by Cairns (3), but more especially in regard to the remarkable change in the length-weight relationship with the development of the ovary, a process which is not accompanied by any very marked effect in this connection in the short-finned species. The possibility of a relationship between ovary development and change in the weight-length relationship of the long-finned eels is suggested by consideration of the Manawatu River samples in the 43-47 in. group, comprising six specimens, average weight 4,319 $\pm$ 323 g. as compared with a value of 5,150 g. predicted from Fig. 2. The value for these Manawatu River eels was excluded from the graph because of the relative absence of ovary development compared with eels from the other localities in the size groups above 38 in. Similarly the abnormally high weight (see Table III) for the single specimen from Lake Ellesmere 1943, in the size range 33-37 in. might be associated with the greater development of ovary as compared with the other immature eels within that size range.

Comparisons between the curves of female long-finned immature and migrant eels of the same length suggest a loss in weight of the order of 10 per cent. associated with transformation of the immature eel to the migrant.

DISSECTION OF EELS AND EXTRACTION OF OIL

After a period generally not exceeding 4 to 6 months of cold storage at 3-5°c., the eels were thawed out and a dissection was made within each size group, to separate the following tissues:— head, trunk, tail, viscera† and liver. The head was severed at the first vertebra, and division of the body into trunk and tail was made by a transverse cut at the vent. In the case of the trunk and tail portions, the total material of the larger eels was too great for convenient handling, and an aliquot was made by cutting each portion into small pieces, which after thorough mixing, were quartered down to a convenient size.

Bulk samples of corresponding parts of each of the eels within the size groups were placed in jars and covered with 95 per cent. alcohol, the alcohol being raised to the boiling point in a water bath, and the heating continued for some 15 minutes. On cooling, the jars were sealed and the samples stored (for not longer than two months) to enable convenient handling with regard to oil extraction.

* This equation is based on the laboratory weighings which as earlier shown are possibly *ca.* 15 per cent. low because of loss of weight on storage.

† The term viscera as used in this paper includes all the organs of the visceral cavity except liver, ovary and kidney.

For the purposes of extracting the oil, the samples were dried in a vacuum oven at *ca.* 60°c. for at least 24 hours, to remove all traces of water. The samples were minced and continuously extracted with petroleum ether, B.P. 40-70°, the extract being replaced at intervals with fresh solvent. When the extract was colourless, about 10 ml. of alcohol were also added to the petroleum ether and extraction again continued, until, on addition of fresh solvent, the extract was colourless. The oil was recovered from the extract by evaporation of the solvent in the usual way, the last traces of solvent being removed *in vacuo* at 100°c. The material insoluble in petroleum ether, extracted after the addition of the alcohol, was dried *in vacuo* and added to solid matter from the extractor, and the total solids, insoluble in petroleum ether were dried to constant weight in a steam oven at 90°c.

RESULTS

PROPORTIONS OF THE DISSECTED TISSUES

Details are given in Appendix 1 of percentages of each of the dissected tissues for each size group, and for each species. As there were inappreciable alterations in the proportions of the dissected tissues with size of eel, the figures from each species have been averaged within each locality as shown in Table IV below. As the larger sizes of long-finned eels contained in some cases appreciable proportions of ovaries, the groups containing eels of length greater than 38 in. have been ommitted in calculating average values.

In both short-finned and long-finned species, the immature eels from Foxton Lakes are shown to have heads which are highly significantly larger than those from other localities studied. In the case of the short-finned eels, the differences between localities in respect of the head size are otherwise insignificant, but in the case of the long-finned eels, significant differences are to be found between the relatively larger heads of the Manawatu eels, as compared with those from the Hutt River, and the Lake Ellesmere eels taken in 1944. The Lake Ellesmere eels taken in 1943 are shown to have significantly larger heads than those from the Hutt River, but not to differ significantly from the Lake Ellesmere eels taken during 1944.

The trunk proportions show considerable uniformity and significant differences are observed only in the case of the reduced amount of trunk in the long-finned eels of the Manawatu River as compared with those from Lake Ellesmere and the Hutt River. The proportion of tail in the Hutt River short-finned eels is found to be significantly greater than in the case of the Foxton Lakes eels. In the case of the tail portions of long-finned eels, the differences between Lake Ellesmere, 1943, and the Manawatu River are highly significant, while those between Lake Ellesmere, 1943, and the Hutt River are as significant as are the differences between the Foxton Lakes and the Manawatu River samples.

The results for the percentage viscera are shown to be fairly uniform and only in the sample of the Foxton Lakes long-finned eels as compared with Lake Ellesmere, 1943, is any significant difference observed. In both short-finned and long-finned eels, wide variations are found in the proportion of liver.

TABLE IV. THE PROPORTIONS OF THE DISSECTED TISSUES EXPRESSED AS A PERCENTAGE OF THE TOTAL WEIGHT

Source		Head	Trunk	Tail	Ovary	Viscera	Liver	
(*a*) Short-finned Eels.								
Lake Ellesmere	1943	4.79±0.61*	43.19±1.52	45.93±0.32	—	5.16±0.78	0.93±0.05	Immature Eels
Lake Ellesmere	1944	5.04±0.50	43.49±0.62	45.67±0.77	—	5.08±0.80	0.72±0.04	
Foxton Lakes	1943	9.84±1.38	41.91±1.19	43.59±1.36	—	4.11±0.50	0.55±0.02	
Hutt River	1943	4.07±0.27	41.91±0.76	49.38±1.28	—	3.55±0.37	1.09±0.06	
Lake Ellesmere	1942	4.8 ±0.43	43.30±1.17	45.60±0.90	3.5	*Ca.* 1.83	0.97±0.07	Migrants
(*b*) Long-finned Eels.								
Lake Ellesmere	1943	9.08±1.01	46.05±0.61	37.02±1.18	0.64	6.17±0.34	1.04±0.01	Immature Eels
Lake Ellesmere	1944	7.42±1.16	44.79±0.89	41.79±2.11	—	5.24±0.46	0.76±0.06	
Foxton Lakes	1943	12.96±0.24	42.16±1.37	39.12±1.38	—	4.78±0.39	0.98±0.18	
Hutt River	1943	7.42±0.87	42.72±0.88	43.17±1.60	—	5.51±0.43	1.18±0.06	
Manawatu River system ...	1943	10.18±0.38	39.12±1.72	44.42±2.23	—	5.26±0.46	1.02±0.05	
Lake Ellesmere	1942	5.5 ±0.4	43.2 ±1.28	36.9 ±1.26	10.7±0.8	2.0 ±0.31	1.7 ±0.05	Migrants

* Standard error.

In the short-finned species the mature eel is shown to contain 3.5 per cent. by weight of ovary at the time of migration, accompanied by a highly significant reduction in the proportion of viscera. A similar change is also observed in the migrating long-finned eel, but here the development of ovary amounting to 10.7 per cent. of the total body weight is accompanied also by a reduction in head size as well as by a highly significant increase in size of liver from 1.00 ($\pm$0.05) to 1.68 per cent. ($\pm$0.05). The relatively larger size of the liver of the migrant is apparently not related to the weight of the fish since immature eels of similar size contained approximately the same proportion of liver as the smaller eels. McCance (24) has also noted in the case of *A. anguilla* L.* that the livers of (yellow) immature eels comprised 1.5 per cent. of the total weight as compared with 2.0 per cent. for the (silver) migrant eels. This may be compared with the higher average value of 3.2 per cent. found by Edisbury, Lovern and Morton (22) for the same species.

Comparing the two species, it will be noted that there is a considerable overlapping in respect of body proportions. Considering mean values and standard errors for the immature specimens, however, the short-finned species as compared with the long-finned has a significantly smaller head (5.93 per cent. $\pm$ 0.74 as compared with 9.48 per cent. $\pm$0.57), a larger proportion of tail (46.14 $\pm$ 0.71 as compared with 41.10 $\pm$ 0.96) and a smaller liver (0.82 per cent. $\pm$ 0.06 as compared with 1.00 $\pm$ 0.05).

OIL CONTENT OF EELS

No significant differences were observed in oil content of short-finned eels within similar size groups, (Appendix 3) so that the combined results only are shown in Fig. 3. For similar reasons, the results for long-finned eels from Lake Ellesmere and Foxton Lakes have been combined. The long-finned eels from the Manawatu and Hutt Rivers, however, were found to be considerably oilier than those obtained in the other localities examined, but not significantly different from each other.

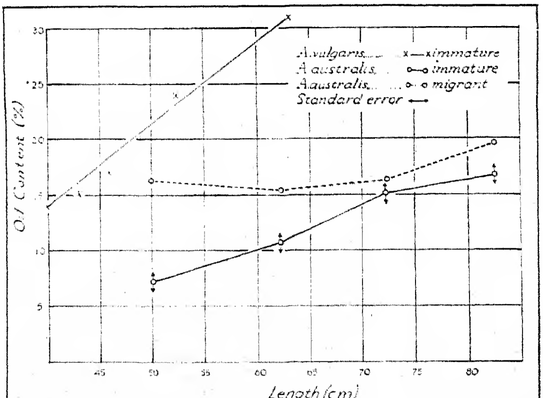


Fig. 3 Oil Content of Eels

* Synonym of *A. vulgaris*.

The total oil content of eels from these two localities has therefore been combined as shown in Fig. 4. For comparative purposes, results obtained by Lovern (15) for the European eel *A. vulgaris* are also shown in Fig. 3 (p. 178).

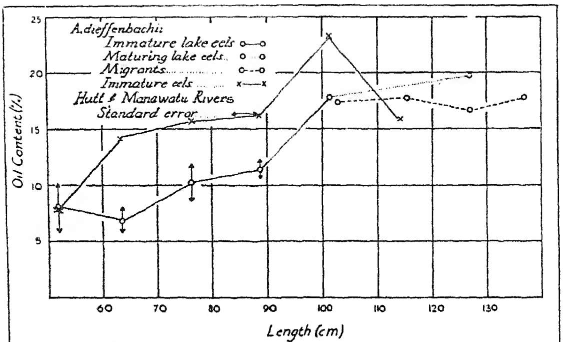


Fig 4 Oil Content of Eels

M.T. 1947

OIL CONTENT OF TISSUES

Details of the oil content of head, trunk, tail viscera and livers for the various groups of eels examined are given in Appendix 3. The main features of these results are illustrated in Figs. 5 and 6. In order to compare the oil contents of the tissues of the immature and maturing long-finned eels with those of the migrants, the data shown in the graph have been restricted to the lake eels, since the Manawatu and Hutt River eels were distinctly oilier than the former. It may be mentioned, however, that in respect of the differences in oil content as between the tail, head and trunk, the eels from the Manawatu River and Hutt River showed the same general trends as the Lake eels examined. The data for the viscera and livers, which were somewhat variable in oil content are not shown in the graph. Since, however, these tissues together contribute only 3.5 $\pm$ 0.5 per cent. and 3.2 $\pm$ 0.7 per cent. of the total oil reserves of the long-finned and short-finned species respectively, their omission from the graph is unimportant.

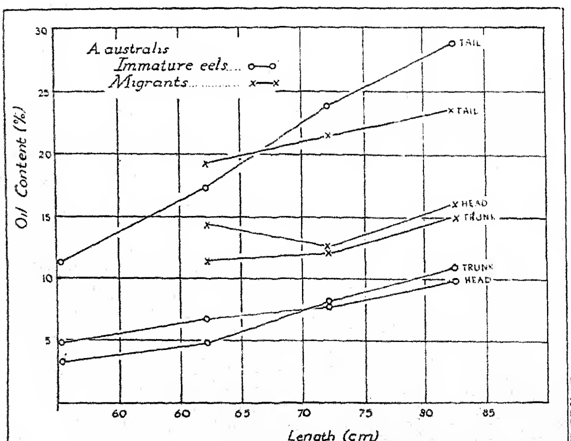


Fig. 5 Oil Content of Tissues

M.T. 1947

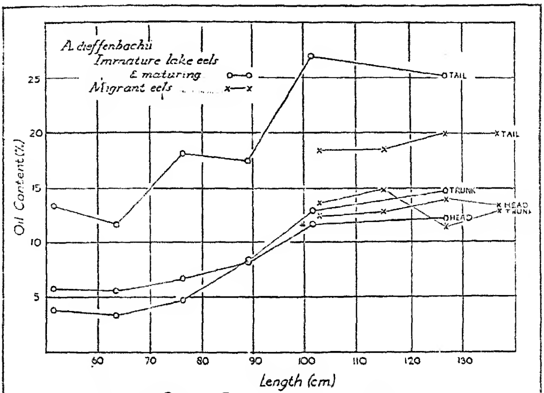


Fig. 6 Oil Content of Tissues

RELATIONSHIPS BETWEEN PERCENTAGE WATER, PERCENTAGE FAT, AND PERCENTAGE PROTEIN

Callow (25) has discussed the relationships which exist between percentage water (W), percentage fat (F) and percentage protein (P) in the meat of British and American beef animals and has calculated linear equations connecting these three variables which, together make up the whole of the bone-free carcase, the protein being regarded as equivalent to the moisture and fat-free residue. The regression equation connecting water and fat content of English beef was found to be as follows :—

$$W = 78.4 - 0.808\ F\ (r = -0.99) \quad . \quad . \quad . \quad (1)$$

Recent work on New Zealand lamb and mutton carcases showed that very similar equations could be applied without serious error to sheep of any origin (26). In the present work no attempt was made to separate bone from flesh and the composition of the tissues given in Appendix 2 are based on the whole carcase, the protein being defined as the fat and moisture free residue. The crude protein value determined in this way is somewhat high in the case of the head tissues but it is believed that the values so obtained for the trunk and tail correspond reasonably closely with the total protein determined from the nitrogen content × 6.25 as in the case of investigations on lamb and mutton carcases. The regression equations for trunk and tail tissues were calculated as follows :—

Short-finned Eels

Trunk $W = 80.17 - 1.073\ F\ (r = -0.96)\ P = 20.35$, S.D. $\pm$ 1.29 . . (2)
Tail $W = 78.24 - 0.848\ F\ (r = -0.97)\ P = 18.71$, S.D. $\pm$ 1.89 . . . (3)

Long-finned Eels

Trunk $W = 79.61 - 0.905\ F\ (r = -0.90)$, $P = 19.56$, S.D. $\pm$ 1.96 . . (4)
Tail $W = 78.11 - 0.805\ F\ (r = -0.96)$, $P = 17.82$, S.D. $\pm$ 2.14 . . (5)

The equations connecting water and fat (oil) in the tail portions of eels are shown to be similar to equation . . . (1) for English beef. It is possible that the equations for the trunk portions, if calculated on a bone free carcase would also give similar values. These results may also be compared with those of Reay, Cutting and Shewan (27)

for herrings. They record the equation W = 80.18 − 0.959 F (r = −0.986). In regard to the crude protein they found little correlation with fat content, which is contrary to Callow's (25) observations on beef but in agreement with our present findings on eels. Since the crude protein values are relatively constant (cf. equations (2), (3), (4) and (5)) it follows that the changes in the composition of eel flesh are largely due to the variations between water and fat (oil) content. As, moreover, moisture may be more readily determined than oil, regression equations connecting oil content with water have been calculated with a view to simplifying the determinations of carcase composition.

Short-finned Eels

Trunk Oil = 69.72 − 0.863 W (r = −0.962) . . . . . . (6)
Tail Oil = 88.47 − 1.117 W (r = −0.973) . . . . . . (7)

Long-finned Eels

Trunk Oil = 72.53 − 0.889 W (r = −0.897) . . . . . . (8)
Tail Oil = 91.30 − 1.149 W (r = −0.962) . . . . . . (9)

DISCUSSION

The increase in oil content of the eel, with size, which has already been noted by Lovern (15) for *A. vulgaris* and by Edisbury, Lovern and Morton (22) for *A. dieffenbachii*, is confirmed by the present results for immature eels of both species examined. (see Figs. 3 and 4). The oil content of *A. vulgaris* is shown to exceed that of *A. australis* comparing samples of the same length. The later maturing *A. dieffenbachii* was found to contain, in general, less oil than either of the other two species at the same length. In this regard, the samples from the Manawatu and Hutt Rivers are shown to differ significantly (see Fig. 4) from the samples of the lake eels and to compare favourably in oil content with the samples of short-finned eels considered at the same length.

The increase in oil content with size, however, seems to be a characteristic of the immature eel only; the migrating short-finned eel shows little, if any, correlation between size and oil content, while the migrant long-finned eel appears to be constant in oil content, irrespective of size. In both species, the oil content of the migrant eel corresponds approximately to the oil content of the largest size group of the immature eel.

McCance (24) on the basis of the oil content (11.2 per cent. and 11.4 per cent.) of two groups of yellow immature eels, *A. anguilla* of average weight 103 g. and 193 g., regarded the occurrence of yellow eels with more than 15 per cent. oil in the muscles, as comprising only a very small proportion in the lakes and rivers of Great Britain. He further stated in reference to Lovern's (15) findings regarding the increase in oil content with the length of the fish, " Be that as it may, these results do not support Lovern's (15) contention that the amount of fat in an eel can be foretold from its length." The present findings, however, in regard to immature New Zealand eels are consistent with Lovern's observations, in respect of the European eel.

In our opinion the two values which McCance gives are not sufficient for any general conclusion to be based on them, and the eels, in any case, appear to be smaller than those on which Lovern based his contention. It is quite conceivable, moreover, that as shown for *A. dieffenbachii* (see Fig. 4) the later stages of development may be preceded by one in which the oil content is reduced as the length increases.

In regard to the four groups of migrant (silver) eels, of average respective weights, 197, 333, 678, and 1,400 g. which McCance (24) examined, his findings of relative constant oil content 26.4 — 29.8 per cent.) irrespective of size are quite consistent with our findings for New Zealand eels ; these eels approach in oil content the largest size of immature eel examined by Lovern.

In considering all these results, however, it must be recognized that the oil content of eels, irrespective of size, may vary with the season. It is possible, for example, that the oil content of the eel during hibernation is different from that obtained after a period of active feeding. The present results must, therefore, be regarded as referring only to eels taken from the localities specified during the months of March and April, after a considerable period of active feeding. The results must also be considered as generally applicable only to groups of 5 to 10 and not to individual eels.

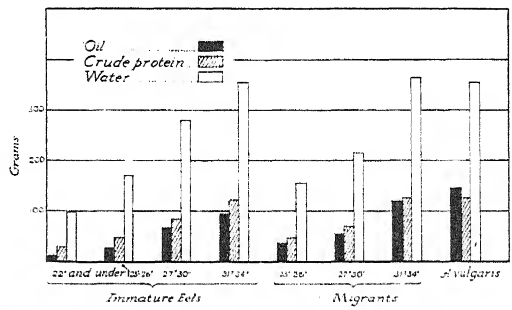


Fig. 7 Weights of Oil, Crude protein & Water in different size groups of A. australis

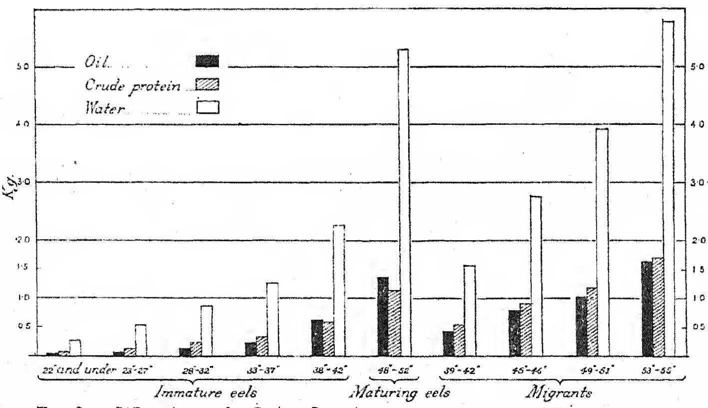


Fig. 8 Weight of Oil, Crude protein and Water in different size groups of A. dieffenbachii.

It is generally recognized that in the growth of animals (cf. Hammond (28)) bone reaches a maximum rate of growth first, then muscle and lastly fat. In the case of certain fish such as, for example, New Zealand ling, (29) only traces (under 0.1 per cent.) of fat (oil) are present,

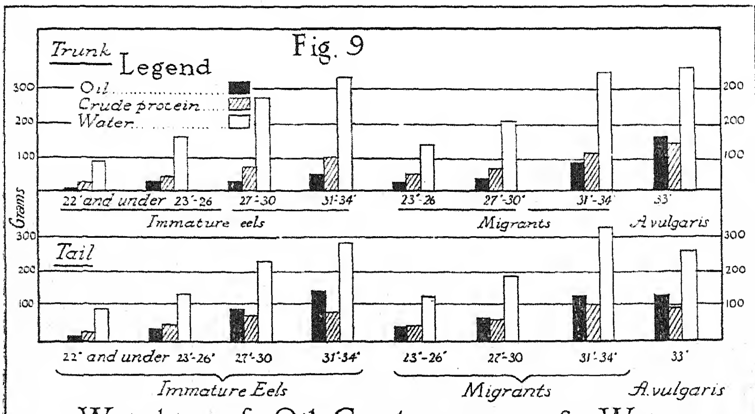
so that in the growth of such fish fat plays no significant part. The present investigation shows that the growth of New Zealand eels is not unlike that of sheep or pigs in respect of the development of fat and protein.

Over the size range studied (see Figs. 7 and 8) the oil contents of *A. australis* and of *A. dieffenbachii* have increased respectively 10 times and 45 times and the protein 4 times and 15 times.

The process of maturing of eels over the size ranges studied, may thus be regarded as one of differential growth, whereby the weight of oil increases with growth of the eel from one third of weight of the protein, until the weight of oil approximately equals that of the protein as in *A. australis* or slightly exceeds it as in *A. dieffenbachii*, i.e. the initially faster growing protein has been overtaken by the later developing oil.

In Fig. 7 are included also data concerning *A. vulgaris* using the oil content derived from the results of Edisbury, Lovern and Morton (22) and assuming the crude protein content to be similar to that of *A. australis*. The migrant short-finned eel in general, shows a greater weight of oil than the immature eel of the same length, but is exceeded in this respect by the more oily *A. vulgaris*. Further examination of the tissues (see Fig. 9) shows that the greater weight of oil in the short-finned migrant as compared with the immature eel of the same length is concentrated in the trunk, the tail section actually showing a loss in weight of oil in the migrant eel, as compared with the immature eel of the same length.

The changes in weight of oil, which appear to take place in the long-finned eels on migrating, are perhaps more profound. Comparing similar size groups (see Fig. 2) it will be seen that the migrant eel is lighter than the maturing* eel of the same length. This loss in weight is consistent with the cessation of feeding which accompanies migration and is associated mainly with a change in the weight of oil as might be anticipated (see Hammond (28)—theory of differential growth).



Weights of Oil, Crude protein & Water in different size groups of A. australis

Trunk and tail sections considered separately

* Term maturing here designates those long-finned eels which contain appreciable proportions of ovaries (above 3 per cent. total weight) but not up to the 10 per cent. characteristic of the migrant eel.

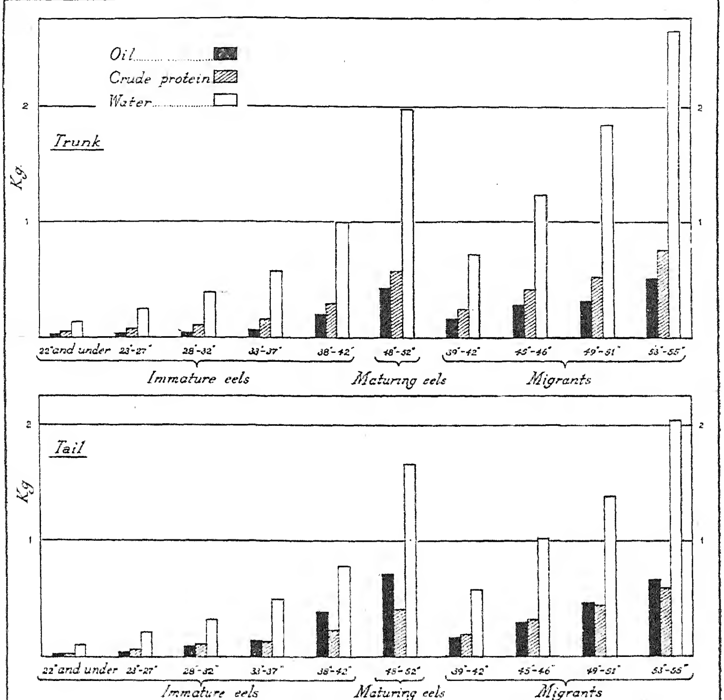


Fig.10 Weights of Oil, Crude protein and Water in different size groups of *A. dieffenbachii*.
(Trunk and Tail sections considered separately)

The latter predicts, that on a sub-maintenance diet the tissues are affected in the reverse order of their development, i.e. fat most, muscle less and bone least. (See for example Pomeroy (30)).

In comparing migrant and immature eels of the same length, the short-finned and long-finned species examined in this investigation showed a general similarity in the loss of weight of oil in the tail section of the migrant eel. In regard to the trunk, however, marked differences were observed between the two species. The trunk portion of the migrant short-finned eel showed a gain in weight of oil as compared with the immature eel of the same length, while the migrant long-finned eel showed a loss in this connection. This difference in behaviour of the oil reserves of the trunk may be associated with the greater development of ovary (see Table IV) in the long-finned eel as compared with the short-finned species.

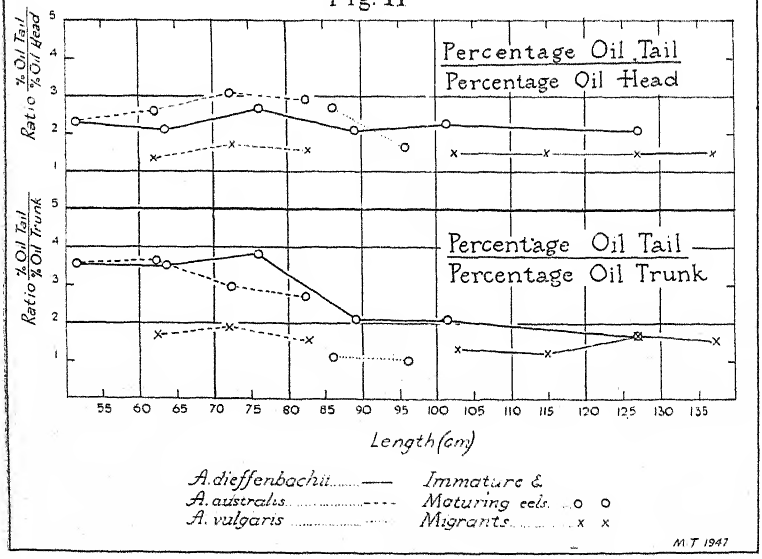
Considering the tissues separately in respect of oil content, the highest concentrations of oil were found in the tail portion, which in the short-finned and long-finned species amounted to as much as 35.14 per cent. and 37.56 per cent. respectively (see Appendix 2). In the migrant eels the ovaries were found to be the most oily of the tissues, containing from 25.7 to 54.5 per cent. oil (see Appendix 2). The uneven distribution of oil was earlier shown by Edisbury, Lovern and Morton (22) for two specimens of *A. dieffenbachii*, especially in the smaller of the

two specimens (1.35 kg.) where the trunk was found to contain 3.5 per cent. as compared with 17.3 per cent. oil found in the tail. In this connection, these workers state—"We are unable to account for a very low oil content of the trunk (i.e. the fore portion of the body, including the visceral cavity) of the smaller eel." The important new feature, however, which emerges from the present work is the fact that although the larger immature eels of both species have similar oil contents to the migrating eels, the latter are clearly distinguished from the former by the more uniform distribution of their oil content. Greater uniformity in the distribution of oil content of the migrant eel as compared with the immature or maturing eel of the same length is achieved in the short-finned eel by a marked increase (ca. 5 per cent.) in the percentage oil in the head and trunk tissues with a decrease in the case of the larger size groups in the percentage oil in the tail (see Fig. 5). In the long-finned eel, greater uniformity in oil content is obtained, mainly, by the drop of some 5 per cent. in the percentage oil present in the tail of the migrant eel, as compared with the maturing eels of the same length, (see Fig. 6) the head and trunk tissues remaining practically unaffected.

The nature of these changes may be observed by considering the ratios :—

$$\frac{\text{percentage oil in tail (T)}}{\text{percentage oil in head (H)}}, \qquad \frac{\text{percentage oil in tail (T)}}{\text{percentage oil in trunk (F)}}.$$

Fig. 11



The values for T/H and T/F show a general similarity in regard to both species, the disparity between the oil content of the tail and the trunk being particularly marked in the immature specimens and sharply contrasted in this respect with *A. vulgaris*, the values for which have been derived from the data of Edisbury, Lovern and Morton (22). With the onset of maturity, the value of T/H appears to remain almost unaffected, there being no transition observed between the immature and migrant eel (see Fig. 11).

In regard to the T/F values, however, the drop in the ratio with increasing length is apparent and the transition in values from the maturing eel to the migrant is shown quite clearly in the case of the long-finned eel. This suggests that the attainment of more uniform distribution of oil in the migrant as compared with the immature eel takes place in two stages, the first being the movement of oil from the tail to the trunk and the last stage, the movement of oil from the trunk to the head*. The values of T/F and T/H for immature and migrant eels are summarized in Table V.

TABLE V. RATIOS $\frac{\text{PERCENTAGE OIL TAIL}}{\text{PERCENTAGE OIL TRUNK}}$ AND $\frac{\text{PERCENTAGE OIL TAIL}}{\text{PERCENTAGE OIL HEAD}}$ OF EELS

SPECIES	Immature Eels		Migrants	
	Oil Tail (T) / Oil Trunk (F)	Oil Tail (T) / Oil Head (H)	Oil Tail (T) / Oil Trunk (F)	Oil Tail (T) / Oil Head (H)
A. australis	3.42±0.27*	2.80±0.21	1.69±0.08	1.51±0.11
A. dieffenbachii	3.29±0.25	2.54±0.19	1.47±0.20	1.47±0.02
A. vulgaris	1.18, 1.03	2.75, 1.72	—	—

* Standard error.

In considering immature specimens of *A. dieffenbachii*, eels of greater length than 38 in. have been excluded. The values for T/F and T/H respectively show that the two species of New Zealand eel are indistinguishable on the basis of this characteristic ; however, values given for *A. vulgaris*, using Edisbury, Lovern and Morton's data, (22) in which the average values are given for the oil contents of two groups of eels, comprising respectively 9 specimens of average weight 1.26 kg. and 8 specimens of average weight 1.53 kg. suggest that this eel may be differentiated from the New Zealand eels, its lower T/F value denoting an almost uniform distribution of oil as between the trunk and tail portions.

TABLE VI. STANDARD DEVIATIONS OF RATIOS T/F AND T/H

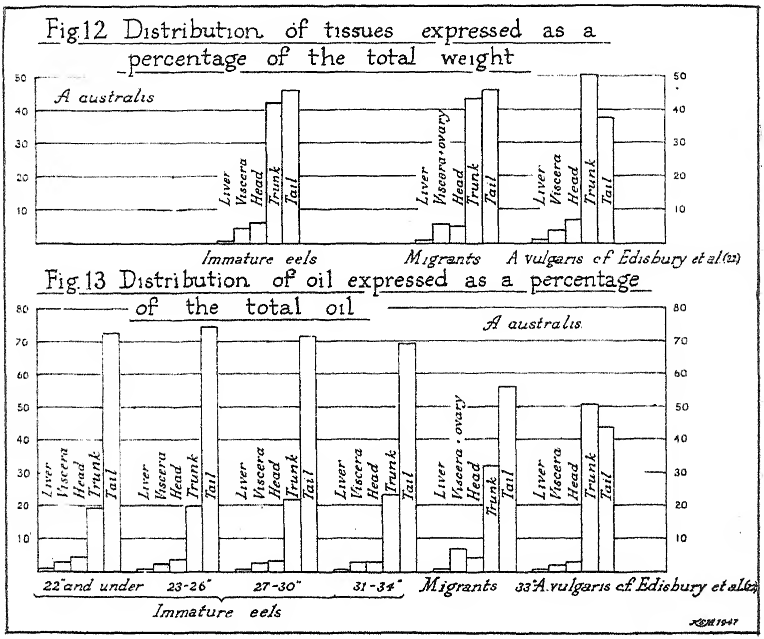
	Immature Eels		Migrants	
	T/F	T/H	T/F	T/H
A. australis	1.06	0.84	0.13	0.19
A. dieffenbachii	1.13	0.85	0.20	0.06

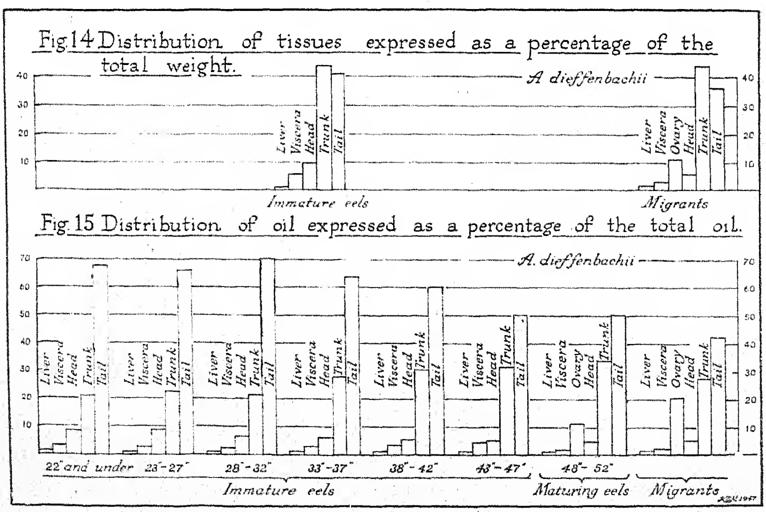
The changes which take place in the oil reserves of *A. australis*, with the development of ovaries may thus be regarded as a fall in the ratio of T/F and T/H to 0.50 and 0.54 respectively of the average value found for immature fish. In the case of *A. dieffenbachii*, the reduction of the T/F value to 0.45 is more marked and the T/H value to 0.58 is less marked than in *A. australis*. In addition to these changes there is a considerable reduction in the standard deviation of T/F and T/H in the migrating eels as compared with the immature eels (see Table VI).

* The interpretation of the last stage is somewhat clearer in the case of *A. australis* because the proportion of head is fairly constant. In the case of *A. dieffenbachii*, however, the interpretation is complicated by the fact that migration is associated with a considerable reduction in the proportion of head.

This remarkable uniformity in the ratio T/F and T/H for samples of migrant eels is stressed in the case of *A. dieffenbachii*, where each size group comprised only two eels and was therefore, subject to the influence of individual variation to a much greater extent than the other groups where five to ten eels were used.

In Figs. 13 and 15 the distribution of oil in eels has been expressed in the case of each tissue as a percentage of the total oil reserves of the fish. For comparison, the relative proportions of these tissues, expressed as a percentage of the total body weight are also given (see Figs. 12 and 14).





Inspection of Figs. 12, 13, 14 and 15 shows that the liver, viscera, trunk and head contribute less oil, while the tail and ovaries contribute more oil than would be anticipated from the weights of these tissues, expressed as a percentage of the total weight of the fish.

In the immature short-finned eel the tail was found to amount to 46 per cent. of the total weight and to contain 75 per cent. of all the oil present in the fish. With the onset of maturity, the proportion of tail was shown to be not significantly affected, while the oil content was reduced to 57 per cent. of the total oil reserves present in the fish. In the immature long-finned eel, the tail portion amounted to only 41 per cent. of the total weight and contained correspondingly less (68 per cent.) of the total oil reserves. With the development of the ovaries (which were relatively much larger than those found for the short-finned eels) the tail amounted to 37 per cent.* of the total body weight, while the spectacular reduction in oil content to 41 per cent. of the total oil reserves of the fish indicates that the tendency for the oil to concentrate in the tail has almost disappeared. Associated with the relative reduction in importance of the tail as an oil reserve, is the appearance of the ovary as an important oil depot, accounting for approximately 20 per cent. of the total oil reserves in the fish. In contrast, the ovaries of the short-finned migrant eel were found to contain only 7 per cent. of the total oil reserves.

In the case of the long-finned eel, the head was found to contain progressively less of the total oil reserves as the fish matured, while the proportion of total oil reserves in the trunk was found to increase during the later stages of maturity. The general increase in the proportion of the total oil reserves in the trunk in the migrant eel as compared with the immature eel, was also found for the short-finned species, but here, no significant differences were found as between mature and immature eels in the proportions of the total oil present in the head. Considering the oil content of the tissues as a percentage of the total oil present in the eel, it will be seen that (see Table VI) the variability of the tissues is much greater in the immature than in the migrant eels.

TABLE VII. SUMMARY OF STANDARD ERRORS OF MEAN VALUES FOR THE OIL CONTENT OF NEW ZEALAND FRESH WATER EELS EXPRESSED AS A PERCENTAGE OF THE TOTAL OIL RESERVES

	Long-finned Eels		Short-finned Eels	
Body Tissue	Immature	Migrants	Immature	Migrants
Liver	0.05–0.13	0.18	0.06–0.25	0.01
Viscera	0.26–0.92	0.24	0.59–1.13	1.00*
Head	0.61–1.47	0.26	0.69–1.18	0.45
Trunk	1.93–4.15	1.12	1.96–2.86	0.09
Tail	1.90–4.64	0.82	2.96–4.04	1.00

* viscera and ovary.

* The apparently lower value for the migrant eel is not necessarily statistically significant, since in 1943 the Lake Ellesmere immature short-finned eels were found to contain 37.04 per cent. ± 1.44 per cent. of tail, while in 1944 the value was 41.05 per cent. ± 1.60 per cent.

The present results afford a basis on which to consider the best methods for industrial utilization of the New Zealand eel. In regard to the immature or non-migrating eels, which are relatively more expensive to catch, it is shown that with increasing size, the possibilities of commercial oil extraction become increasingly favourable. By selecting short-finned eels of length greater than 27 in. (which a conservative estimate of present data (see Table III) suggests comprise not less than 30 per cent. of total numbers, or rather more than 50 per cent. of the total weight), and again, by selecting the tail portions, approximately 70 per cent. of the oil originally present in the fish would be retained in a highly concentrated form (approximately 23.5 — 29 per cent. of the total tissue being oil, as compared with 15 — 17 per cent. in the whole fish.

Industrial fish (body) oils are generally produced from raw materials containing less than 25 per cent. oil. Pilchard oil, the main industrial fish oil of British Columbia, amounting to some 2 million gallons per annum, is produced from fish yielding from 12 to 24 per cent. oil (31).

In the case of the long-finned eels, the immature eels from Lake Ellesmere and Foxton Lakes are less suitable for oil extraction, the total oil content of the largest size eels (above 38 in.) amounting to 18-20 per cent., while the next size groups (28-32 in. and 33-37 in.) contain only 10-12 per cent. oil with 18 per cent. oil in the tail. As however, the largest eels probably do not constitute generally the greater part by weight of the immature population, it will be appreciated that the opportunities of obtaining material rich in oil from this species, in the localities mentioned, are more limited than in the case of the short-finned eels. The possibilities of obtaining useful material for oil extraction from the long-finned eels from the Manawatu and Hutt Rivers would appear to be greater. All size groups of immature eels above 27 in. which comprise some 80 per cent. of the total weight of the population (see Table III) are shown to contain 16-23 per cent. oil with 20-37 per cent. in the tail. Migrant eels which contain 15-20 per cent. of oil irrespective of size and species offer useful material for oil extraction, but in this case the selection of the tail portions would obviously not be warranted. It is generally considered, however, that eels are in their best condition as food at the migrating stage (32). Variations in oil content with size of fish, as well as the variations in the distribution of oil, would undoubtedly require consideration in regard to the present project for canning eels in New Zealand. In the interests of securing a uniform pack in respect of oil content, it may be desirable to pay attention to the size of the eel, and to include in each tin portions from the tail and trunk, rather than tissues taken from one part of the eel only. The importance of paying attention to oil content is emphasized by the fact that fishes such as salmon, herring, pilchards and sardines are more satisfactory for canning than are non-oily fish such as cod. The question of the production of soft bones in canning is known to be related to the temperature and time retorting of the can. From experimental evidence, it appears that a soft bone can be produced, without softening of the flesh, if the eel is canned soon after catching. In this connection, consideration should be given to the transport of eels in live condition, using sacks with wet grass and storage of the eels in ponds, in association with the canning factory.

The question of sending frozen eels to Great Britain has been considered, but so far no market has been established. It is known that the London market requires a small size eel, preferably one not exceeding 2 lb. in weight. Comparisons between New Zealand eels and eels (*A. vulgaris*) from Great Britain show that the small immature eels from New Zealand are likely to be quite different in their properties from those obtained in Great Britain, as they contain less than half the oil content. Moreover, in contrast to the British eel, the oil content of the New Zealand immature eel is far from evenly distributed as between the trunk and tail portions.

The short-finned eel from Lake Ellesmere which comprises the greater proportion of the migrant population, weighs generally well under 2 lb. and approaches the British eel in respect of oil content and distribution is more likely to meet the requirements of the London market. It is only in respect of the tail portions of the larger sizes of New Zealand eels that the oil content approaches that of the British eel, and, in the case of the immature eels, consideration should perhaps be given to the possibility of marketing the tail portion of the fish separately, with the manufacture of the remainder of the fish into poultry meal or fertilizer. Consideration should be given to the removal of the last two or three inches of the tail which is mainly fin and vertebrae, with practically no edible quantity of fish.

Much could be said in regard to the nutritive value of eels, which afford food with a similar protein value to that of beef but with a higher calorific value. The eel by virtue of its vitamin A and D content, offers the combined food values of butter and beef. Final considerations of the value of the eel and the best method of utilization are, however, dependent on further investigations of the vitamin A and D content, and the methods for oil extraction and for canning.

Acknowledgments

The authors are indebted to the former Chief Inspector of Fisheries, A. E. Hefford, for his interest and co-operation in securing samples. D. F. Hobbs, Senior Freshwater Biologist, placed at our disposal material and information which he collected during his investigations of the Lake Ellesmere eel population in 1942; he also organized a scheme for the collection of further materials from other sources during his absence in the forces. The material from the Manawatu River and Foxton Lakes was collected through the courtesy of the Wellington Acclimatization Society by Ranger T. Andrews, while subsequent collections were made by the late M. Hope at Lake Ellesmere. Eels from the Hutt River were supplied by D. Cairns, M.Sc., Officer-in-Charge of the Information Bureau of the Department of Scientific and Industrial Research, who also gave help on the biological aspects of this work. The regression equations connecting oil and water content were calculated by I. Dick of the Biometrics Section of the Department of Scientific and Industrial Research. The authors wish to thank these workers as well as others who have made possible the publication of this paper.

REFERENCES

(1) HEFFORD, A. E.: Report on Fisheries for the year ending 31st March, 1934. Marine Dept., Wellington, New Zealand.

(2) HEFFORD, A. E.: Report on Fisheries for the year ending 31st March, 1945. Marine Dept., Wellington, New Zealand.

(3) CAIRNS, D. (1941-1942): *N.Z. J. Sci. and Tech.*, *23*, 53B-72B; 132B-148B; 173B-178B.

(4) CAIRNS, D. (1938): Research Report. *Southland Acc. Soc., 70th. Ann. Rept.*

(5) CAIRNS, D. (1945): *N.Z. Sci. Rev.*, *2*, No. 4, 3.

(6) HOBBS, D. F.: Marine Dept., Wellington. Private communication.

(7) WEBLING, J. K. L.: Shell Oil Co. of New Zealand, Ltd., Wellington. Private communication.

(8) Schmidt, J. (1935): Distribution of Fresh Water Eels throughout the World. Part II. The Indo-Pacific Region. *Memoires de l'Academie Royale des Sciences et des Lettres de Danemark, Copenhague. Sect. des Sciences 8 me serie. t. × No. 4.* (In English).

(9) EGE, V. H. (1939): "Dana Report No. 16." Oxford University Press., London.

(10) WHITE, G. F. (1912): *J. Ind. Eng. Chem.*, *4*, 106.

(11) WIEHR, H. (1934): *Fettchem Umschau*, *41*, 71.

(12) DENZ, F. A. and SHORLAND, F. B. (1934): *N.Z. J. Sci. and Tech.*, *15*, 327.

(13) ONO, T. (1935): *J. Agr. Chem. Soc., Japan*, *11*, 773.

(14) SHORLAND, F. B. and MCINTOSH, I. G. (1936): *Biochem. J.*, *30*, 1775.

(15) LOVERN, J. A. (1938): *Biochem. J.*, *32*, 1214.

(16) HILDITCH, T. P. and TERLESKI, J. T. (1937): *J. Soc. Chem. Ind.*, *56*, 315T.

(17) LOVERN, J. A. (1942): The Composition of the Depot Fats of Aquatic Animals. *Food Invest. Bd., Spec. Rpt.*, *51*.

(18) LOVERN, J. A. (1940): *Biochem. J.*, *34*, 704.

(19) *Rept. Med. Res. Counc., London.* (1926-7), 21.

(20) CUNNINGHAM, M. M. (1935): *N.Z. J. Sci. and Tech.*, *17*, 563.

(21) WEEBER, E. R. (1945): *Biochem. J.*, *39*, 264.

(22) EDISBURY, J. R., LOVERN, J. A. and MORTON, R. A. (1937): *Biochem. J.*, *31*, 416.

(23) WARD, J. F. (1936): *Chem. and Drugg.*, *125*, 267.

(24) MCCANCE, R. A. (1944): *Biochem J.*, *38*, 474.

(25) CALLOW, E. H. (1942): *Chem. and Ind.*, *61*, 381.

(26) SHORLAND, F. B., de la MARE, P. B. D., BARNICOAT, C. R. and SORRELL, M. P. (1947): *N.Z. J. Sci. and Tech.*, *29*, (*Sec. A*), 76-90

(27) REAY, G. A., CUTTING, C. L. and SHEWAN, J. M. (1943): *J. Soc. Chem. Ind.*, *62*, 77T.

(28) HAMMOND, J. (1942): *Endeavour*, *1*, 131.

(29) SHORLAND, F. B. (1938): *Biochem. J.*, *32*, 488.

(30) POMEROY, R. W. (1941): *J. Agr. Sci.*, *31*, 50.

(31) BROCKLESBY, H. N. (1941): The Chemistry and Technology of Marine Animal Oils with particular Reference to those of Canada. *Fish. Res. Bd. of Can., Ottawa, Bull. LIX.*

(32) DEWBERRY, E. B. (1942): *Food Manufacture*, *17*, 353.

APPENDICES

APPENDIX 1.

THE PROPORTIONS OF THE DISSECTED TISSUES EXPRESSED AS A PERCENTAGE OF THE TOTAL WEIGHT

Short-finned Eels 22 in. and under.

Body Tissue	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)
Liver	0.93	0.51	0.93	0.69
Viscera	2.93	3.35	4.42	4.61
Head	4.56	6.83	6.32	6.31
Trunk	41.41	42.34	43.11	45.19
Tail	50.17	46.97	45.22	43.20

Short-finned Eels 23 in. - 26 in.

Body Tissue	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Migrants Lake Ellesmere (1942)
Liver	1.13	0.61	0.84	0.72	0.9
Viscera	3.59	3.38	3.93	5.12	1.0
Head	4.06	8.19	4.22	4.80	4.8
Trunk	42.87	44.31	44.56	43.59	44.2
Tail	48.35	43.51	46.45	45.77	46.1
					3.0†

† Includes ovary.

Short-finned Eels 27 in. - 30 in.

Body Tissue	Immature specimens				Migrants
	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Lake Ellesmere (1942)
Liver	1.15	0.53*	0.90	0.63	0.9
Viscera	3.85	4.23	5.09	4.78	4.8†
Head	3.84	12.56	5.10	5.16	4.1
Trunk	41.68	42.37	42.45	42.85	45.7
Tail	49.48	40.31	46.46	46.58	44.5

* Recalculated from dry matter. † Includes ovary.

Short-finned Eels 31 in. - 34 in.

Body Tissue	Immature specimens			Migrants
	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Lake Ellesmere (1942)
Liver	0.53	1.06	0.83	1.1
Viscera	5.47	7.21	5.83	1.2
Head	11.77	3.52	3.90	5.6
Trunk	38.60	42.64	42.35	42.0
Tail	43.63	45.57	47.09	46.1
				4.0†

† Includes ovary.

APPENDIX 1—*Continued*

Long-finned Eels 22 in. and under.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)
Liver	0.94	1.05	0.67	1.07	0.80
Viscera	4.02	4.79	4.63	6.01	4.58
Head	9.50	5.29	13.61	6.34	6.36
Trunk	35.40	41.47	39.65	46.17	43.28
Tail	50.14	47.40	41.44	40.41	44.98

Long-finned Eels 23 in. - 27 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)
Liver	1.01	1.14	0.93	1.02	0.74
Viscera	5.37	6.27	4.24	7.16	4.61
Head	10.65	7.19	12.91	10.90	6.25
Trunk	38.29	41.55	44.94	44.28	44.20
Tail	44.68	43.85	36.98	36.64	44.20

Long-finned Eels 28 in. - 32 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)
Liver	0.96	1.32	1.50*	1.01	0.90
Viscera	5.02	6.24	4.34	5.55	6.32
Head	9.97	9.50	12.56	10.42	6.36
Trunk	40.62	42.61	40.05	46.98	44.11
Tail	43.43	40.33	41.55	36.04	42.31

* Recalculated from dry matter.

Long-finned Eels 33 in. - 37 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)
Liver	1.17*	1.20	0.82	1.05	0.59
Viscera	6.62	4.73	5.91	5.97	5.47
Head	10.61	7.71	12.75	8.65	10.93
Trunk	42.26	45.24	44.01	46.78	47.32
Tail	39.34	41.12	36.51	34.98	35.69
				2.57†	

* Recalculated from dry matter. † Includes ovary.

Long-finned Eels 38 in. - 42 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)
Liver	1.05	0.98	1.28	0.91
Viscera	5.87	3.86	7.06	7.07
Head	10.41	6.04	5.27	9.63
Trunk	40.00	43.00	49.27	43.32
Tail	42.67	44.01	37.12	39.07
Ovary		2.11		

APPENDIX 1—*Continued*

Long-finned Eels.

Body Tissue	43 in.-47 in.	48 in.-52 in.	
	Manawatu River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1944)
Liver	1.07	1.39	1.01
Viscera	6.84	1.23	2.29
Head	13.38	6.98	7.65
Trunk	40.77	45.30	42.14
Tail	37.94	38.90	43.40
Ovary		6.20	3.51

Long-finned Eels. Lake Ellesmere, 1942. (Migrant eels).

Length (in.)	Liver	Viscera	Head	Trunk	Tail	Ovary
39–42	1.9	1.4	5.4	39.6	40.3	11.4
45–46	1.6	2.8	6.6	43.1	37.4	8.5
49–51	1.6	1.7	5.3	45.6	34.5	11.3
53–55	1.6	2.2	4.7	44.2	35.6	11.7

APPENDIX 2.

PERCENTAGE CRUDE PROTEIN, WATER AND OIL OF NEW ZEALAND EELS

Short-finned Eels

Locality	Size (Inches)	Head			Trunk			Tail		
		Protein	Water	Oil	Protein	Water	Oil	Protein	Water	Oil
Hutt River, 1943. (Immature)	22 and under	30.30	64.64	5.06	23.41	73.32	3.27	19.86	68.70	11.44
	23–26	26.20	68.39	5.41	20.15	75.43	4.42	22.68	61.52	15.80
	27–30	23.85	68.38	7.77	18.69	73.86	7.45	17.16	59.59	23.25
Lake Ellesmere, 1944. (Immature)	22 and under	25.52	70.34	4.14	18.78	80.04	1.18	18.03	76.84	5.13
	23–26	25.93	68.04	6.03	19.59	77.32	3.09	18.19	62.02	19.79
	27–30	21.61	71.16	7.23	21.16	70.96	7.88	16.97	55.79	27.24
	31 and over	20.07	69.68	10.25	20.14	67.69	12.17	16.76	48.10	35.14
Foxton Lakes. 1943. (Immature)	22 and under	25.31	69.18	5.51	20.48	75.80	3.72	19.83	63.77	16.40
	23–26	23.08	70.32	6.60	20.29	74.16	5.55	21.21	64.85	13.94
	27–30	21.15	74.33	4.52	18.61	76.43	4.96	18.38	60.71	20.91
	31 and over	20.66	71.11	8.23	19.99	71.02	8.99	15.54	55.80	28.66
Lake Ellesmere, 1942. (Migrants)	23–26	25.1	60.7	14.2	21.7	67.0	11.3	20.0	60.9	19.1
	27–30	25.4	62.2	12.4	20.9	67.4	11.7	18.9	59.8	21.3
	31–34	23.4	60.8	15.8	21.0	64.1	14.9	18.4	58.3	23.3

APPENDIX 2—*Continued*

Long-finned Eels

Locality	Size (Inches)	Head Protein	Head Water	Head Oil	Trunk Protein	Trunk Water	Trunk Oil	Tail Protein	Tail Water	Tail Oil
Hutt River, 1943. (Immature)	22 and under	24.92	68.86	6.22	20.70	72.11	7.19	17.52	73.28	9.20
	23–27	25.28	67.96	6.76	16.80	77.11	6.09	15.12	59.18	25.70
	28–32	30.50	63.15	6.35	19.05	76.14	4.81	16.68	64.74	18.58
	33–37	22.30	69.38	8.32	18.22	73.46	8.32	17.57	58.13	24.30
	38–42	24.70	64.96	10.34	17.39	63.99	18.62	13.82	55.46	30.72
Lake Ellesmere, 1944. (Immature)	22 and under	22.39	71.28	6.33	18.85	76.63	4.52	18.43	60.76	20.81
	23–27	23.58	70.46	5.96	19.63	77.13	3.24	18.52	67.60	13.88
	28–32	23.70	70.49	5.81	21.47	72.85	5.68	22.00	65.29	12.71
	33–37	24.44	68.83	6.73	20.06	72.11	7.83	16.17	65.67	18.16
	38–42	21.85	68.70	9.45	19.56	69.89	10.55	15.97	54.79	29.24
	48–52	18.67	71.02	10.31	18.41	66.41	15.18	14.72	55.23	30.05
Manawatu River, 1943. (Immature)	22 and under	21.11	74.08	4.81	21.80	75.24	2.96	18.83	69.02	12.15
	23–27	19.35	72.00	8.65	22.05	68.66	9.29	17.08	62.55	20.37
	28–32	17.82	73.59	8.59	16.43	76.41	7.16	17.73	44.71	37.56
	33–37	21.58	68.72	9.70	18.01	71.09	10.90	16.29	56.30	27.41
	38–42	21.19	66.24	12.57	15.98	68.11	15.91	15.35	51.85	32.80
	43–47	20.07	69.41	10.52	17.80	70.09	12.11	19.80	60.05	20.15
Foxton Lakes, 1943. (Immature)	22 and under	24.78	69.86	5.36	21.93	73.92	4.15	20.80	67.80	11.40
	23–27	25.24	69.19	5.57	22.39	74.45	3.16	20.79	66.72	12.49
	28–32	29.68	64.19	6.13	17.62	79.14	3.24	20.10	64.14	15.76
	33–37	23.64	69.55	6.81	22.61	70.35	7.04	18.90	59.15	21.95
	48–52	19.31	66.68	14.01	19.71	66.12	14.17	14.92	64.56	20.52
Lake Ellesmere, 1942. (Migrants)	39–42	21.6	66.0	12.4	21.7	64.7	13.6	20.3	61.2	18.5
	45–46	21.4	65.8	12.8	21.6	63.5	14.9	19.1	62.3	18.6
	49–51	21.2	64.8	14.0	19.5	69.0	11.5	19.2	60.8	20.0
	53–55	20.8	65.8	13.4	19.3	67.7	13.0	17.7	62.3	20.0

COMPOSITION OF OVARIES

Long-finned Eels

Locality	Size (Inches)	Per Cent. Whole Fish	Protein	Water	Oil	
Lake Ellesmere 1943	33–37	2.57	10.53	58.59	30.88	Immature
Lake Ellesmere 1944	48–52	3.61	9.67	40.88	49.45	,,
Hutt River 1943	38–42	2.11	7.00	38.47	54.53	,,
Foxton Lakes 1943	48–52	6.20	11.16	46.41	42.43	,,
Lake Ellesmere 1942	39–42	11.4	15.4	55.8	28.8	Migrants
	45–46	8.5	13.5	51.8	34.7	,,
	49–51	11.3	14.3	56.1	29.6	,,
	53–55	11.7	16.3	51.3	32.4	,,

Short-finned Eels

Locality	Size (Inches)	Per Cent. Whole Fish	Protein	Water	Oil	
Lake Ellesmere 1942	23–26	3.0	10.6	64.7	24.7	Migrants
	31–34	4.0	10.4	50.6	39.0	,,

APPENDIX 3.

PERCENTAGE OIL IN TISSUES OF NEW ZEALAND FRESH WATER EELS

(*a*) *Short-finned Eels.*

22 in. and under.

Body Tissue	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error
Liver	5.38	1.57	7.14	5.76	4.96±1.37
Viscera	3.93	6.27	9.55	2.73	5.62±1.30
Head	5.06	5.51	4.56	4.14	4.82±0.36
Trunk	3.27	3.72	4.43	1.18	3.15±0.70
Tail	11.44	16.40	11.25	5.13	11.06±2.30
Total	7.49	9.87	7.78	3.18	7.08±1.40

23 in. - 26 in.

Body Tissue	Immature eels					Migrants
	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error	Lake Ellesmere (1942)
Liver	5.21	3.60	7.10	4.83	5.19±0.72	6.5
Viscera	1.14	9.13	9.73	2.37	5.59±2.09	24.7† 11.8*
Head	5.41	6.60	8.33	6.03	6.59±0.63	14.2
Trunk	4.42	5.55	5.90	3.09	4.74±0.80	11.3
Tail	15.80	13.94	19.24	19.79	17.19±1.40	19.1
Total	9.85	9.40	12.35	10.85	10.61±0.67	15.4

* viscera. † ovary.

27 in. - 30 in.

Body Tissue	Immature eels					Migrants
	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error	Lake Ellesmere (1942)
Liver	5.38	4.26	7.56	4.00	5.30±0.81	4.9
Viscera	7.64	5.28	13.78	6.01	8.18±1.93	20.4*
Head	7.77	4.52	10.99	7.23	7.63±1.33	12.4
Trunk	7.45	4.96	11.59	7.88	7.97±1.37	11.7
Tail	23.25	20.91	22.80	27.24	23.55±1.33	21.3
Total	15.26	11.34	16.85	16.76	15.05±1.29	16.4

* viscera.

31 in. - 34 in.

Body Tissue	Immature eels				Migrants
	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error	Lake Ellesmere (1942)
Liver	7.04	10.43	5.53	7.67±1.44	8.0
Viscera	8.19	15.01	5.89	9.70±2.74	33.7*
Head	8.23	10.59	10.25	9.69±0.74	15.8
Trunk	8.99	10.80	12.17	10.65±0.92	14.9
Tail	28.66	22.25	35.14	28.68±3.18	23.3
Total	17.44	16.42	16.71	16.86±0.30	19.7

* viscera.

APPENDIX 3—*Continued*

(*b*) *Long-finned Eels.*

Immature eels 22 in. and under.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Mean Value (Rivers)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error (Lakes)
Liver	4.39	4.45	4.42	12.10	3.54	3.53	6.39 ± 2.84
Viscera	5.68	5.07	5.38	8.63	2.29	3.98	4.97 ± 1.88
Head	4.81	6.22	5.52	5.36	8.31	6.33	5.67 ± 1.12
Trunk	2.96	7.19	5.08	4.15	2.52	4.52	3.73 ± 0.61
Tail	12.15	9.20	10.68	11.40	7.55	20.81	13.25 ± 3.89
Total	7.87	7.95	7.91	7.58	4.92	11.93	8.14 ± 2.04

Immature eels 23 in. - 27 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Mean Value (Rivers)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error (Lakes)
Liver	7.21	6.33	6.77	6.19	3.66	6.48	5.41 ± 0.89
Viscera	3.63	5.24	4.44	4.81	2.81	3.03	3.55 ± 0.63
Head	8.65	6.76	7.70	5.57	5.13	5.96	5.55 ± 0.24
Trunk	9.29	6.09	7.69	3.16	3.60	3.24	3.33 ± 0.13
Tail	20.37	25.70	23.04	12.49	8.25	13.88	11.54 ± 1.69
Total	13.85	14.71	14.28	7.02	5.41	8.13	6.85 ± 0.79

Immature eels 28 in. - 32 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Mean Value (Rivers)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error (Lakes)
Liver	7.09	3.67	5.38	2.18	4.52	4.90	3.87 ± 0.85
Viscera	11.33	5.68	8.50	5.09	4.91	2.58	4.19 ± 0.81
Head	8.59	6.35	7.47	6.13	8.15	5.81	6.70 ± 0.74
Trunk	7.16	4.81	5.99	3.24	5.37	5.68	4.76 ± 0.77
Tail	37.56	18.58	28.07	15.76	26.04	12.71	18.17 ± 4.04
Total	20.70	10.54	15.62	8.87	13.21	8.49	10.19 ± 1.52

Immature eels 33 in. - 37 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Mean Value (Rivers)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error (Lakes)
Liver	19.81	5.73	12.77	6.94	3.54	8.67	6.38 ± 1.51
Viscera	13.30	9.24	11.27	2.76	2.54†	2.44	2.58 ± 0.10
Head	9.70	8.32	9.01	6.81	10.91	6.73	8.15 ± 1.38
Trunk	10.90	8.32	9.61	7.04	9.82	7.83	8.23 ± 0.83
Tail	27.41	24.30	25.86	21.95	12.32	18.16	17.48 ± 2.56
Total	17.32	14.90	16.11	12.20	10.82	11.10	11.37 ± 0.54

† ovary 30.88 per cent. oil.

Immature eels 38 in. - 42 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Mean Value (Rivers)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value (Lakes)
Liver	13.01	7.41	10.21	9.62	6.60	8.11
Viscera	17.44	8.77	13.10	3.27	12.58	7.92
Ovary	——	54.53	——	——	——	——
Head	12.57	10.34	11.46	13.67	9.45	11.56
Trunk	15.91	18.62	17.27	15.41	10.55	12.98
Tail	32.80	30.72	31.76	24.98	29.24	27.11
Total	22.84	23.71	23.28	17.94	17.86	17.90

APPENDIX 3—*Continued*

Immature eels.

Body Tissue	43in.-47in.	48 in. - 52 in.		Mean Value (Lakes)
	Manawatu River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1944)	
Liver	10.44	18.42	7.53	12.98
Viscera	21.57	7.72	9.01	8.37
Ovary	———	42.23	49.45	45.84
Head	10.52	14.01	10.31	12.16
Trunk	12.11	14.17	15.18	14.68
Tail	20.15	20.52	30.05	25.28
Total	15.58	17.97	21.87	19.92

Migrant Eels. Lake Ellesmere, 1942.

	Size 39 in.-42 in.	Size 45 in.-46 in.	Size 49 in.-51 in.	Size 53 in.-55 in.	Mean and Std. Error
Liver	20.8	16.7	7.7	9.3	13.6±3.10
Viscera and Ovary	28.8	34.7	29.6	32.4	31.4±1.30
Head	12.4	12.8	14.0	13.4	13.2±0.35
Trunk	13.6	14.9	11.5	13.0	13.3±0.71
Tail	18.5	18.6	20.0	20.0	19.3±0.42
Total	17.4	17.8	16.6	17.8	17.4±0.29

APPENDIX 4.

DISTRIBUTION OF OIL IN TISSUES OF NEW ZEALAND FRESH WATER EELS
(expressed as a percentage of the total oil).

(*a*) *Short-finned Eels.*

Immature eels 22 in. and under.

Body Tissue	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error
Liver	0.7	0.1	0.9	1.3	0.8±0.25
Viscera	1.5	2.1	5.4	4.0	3.2±0.89
Head	3.1	3.8	3.7	8.2	4.7±1.18
Trunk	18.1	16.0	24.6	16.8	18.9±1.96
Tail	76.6	78.0	65.4	69.7	72.4±2.96

Immature eels 23 in. - 26 in.

Body Tissue	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error	Migrants Lake Ellesmere (1942)
Liver	0.6	0.2	0.5	0.3	0.4±0.09	0.4
Viscera	0.4	3.3	3.1	1.2	2.0±0.71	0.8*
						5.0†
Head	2.2	5.8	2.8	2.6	3.4±0.82	4.4
Trunk	19.2	26.2	21.3	12.4	19.8±2.86	32.4
Tail	77.6	64.5	72.3	83.5	74.5±4.04	57.0

* viscera. † ovary.

APPENDIX 4—*Continued*

Immature eels 27 in. - 30 in.

Body Tissue	Hutt River (1943)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error	Migrants Lake Ellesmere (1942)
Liver	0.4	0.2	0.4	0.2	0.3±0.06	0.3
Viscera	1.9	2.0	4.2	1.7	2.5±0.59	6.0†
Head	2.0	5.0	3.3	2.2	3.1±0.69	3.1
Trunk	20.3	18.5	29.2	20.2	22.1±2.42	32.6
Tail	75.4	74.3	62.9	75.7	72.0±3.00	58.0

† ovary.

Immature eels 31 in. - 34 in.

Body Tissue	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value and Std. Error	Migrants Lake Ellesmere (1942)
Liver	0.2	0.5	0.2	0.3±0.10	0.4
Viscera	2.6	5.3	1.5	3.2±1.13	1.0
					7.9†
Head	5.6	2.5	1.8	3.2±1.17	4.5
Trunk	19.9	27.8	22.9	23.5±2.30	31.7
Tail	71.7	63.9	73.6	69.8±3.00	54.5

† ovary.

Migrant eels. Lake Ellesmere, 1942.

	Liver	Viscera and Ovary	Head	Trunk	Tail
Av.	0.4	6.9	4.0	32.2	56.5
S.D.	0.02	1.74	0.78	0.15	1.80
S.E.	0.01	1.00	0.45	0.09	1.00

(*b*) *Long-finned Eels.*

Immature eels 22 in. and under.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Mean Value (Rivers)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value (Lakes)	Mean Value and Std. Error of all samples
Liver	0.5	0.5	0.5	1.0	0.7	0.2	0.6	0.6±0.13
Viscera	2.9	3.0	3.0	5.2	2.8	1.5	3.2	3.1±0.60
Head	5.8	4.1	4.9	9.6	10.8	3.4	8.0	6.8±1.47
Trunk	13.4	37.5	25.5	21.8	23.6	16.4	20.6	22.5±4.15
Tail	77.4	54.9	66.1	62.4	62.0	78.5	67.6	67.0±4.64

Immature eels 23 in. - 27 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Mean Value (Rivers)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value (Lakes)	Mean Value and Std. Error of all samples
Liver	0.5	0.5	0.5	0.8	0.7	0.6	0.7	0.7±0.07
Viscera	1.4	2.2	1.8	2.9	3.7	1.7	2.7	2.4±0.49
Head	6.7	3.3	5.0	10.3	10.3	4.6	8.4	7.0±1.43
Trunk	25.7	17.2	21.5	20.2	29.5	17.6	22.4	22.0±2.40
Tail	65.7	76.8	71.2	65.8	55.8	75.5	65.8	67.9±3.82

APPENDIX 4—*Continued*

Immature eels 28 in. - 32 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Mean Value (Rivers)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value (Lakes)	Mean Value and Std. Error of all samples
Liver	0.3	0.5	0.4	0.4	0.4	0.5	0.4	0.4±0.05
Viscera	2.8	3.3	3.0	2.5	2.0	1.9	2.1	2.5±0.26
Head	3.9	5.7	4.8	8.7	6.4	4.4	6.5	5.8±0.85
Trunk	14.2	19.5	16.9	14.6	19.1	30.0	21.3	19.5±2.84
Tail	78.8	71.0	74.9	73.8	72.1	63.2	69.7	71.8±2.52

Immature eels 33 in. - 37 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Mean Value (Rivers)	Foxton Lakes (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value (Lakes)*	Mean Value and Std. Error of all samples
Liver	0.1	0.5	0.3	0.5	0.3	0.5	0.4	0.4±0.10
Viscera	5.1	2.9	4.0	1.3	1.4 7.3†	1.2	1.3	2.6±0.92
Head	6.0	4.3	5.1	7.1	8.7	6.6	6.9	6.0±0.61
Trunk	26.6	25.3	26.0	25.4	42.4	33.4	29.4	27.7±1.93
Tail	62.2	67.0	64.6	65.7	39.9	58.3	62.0	63.3±1.90

* Excluding Lake Ellesmere, 1943. † ovary.

Immature eels 38 in. - 42 in.

Body Tissue	Manawatu River (1943)	Hutt River (1943)	Lake Ellesmere (1943)	Lake Ellesmere (1944)	Mean Value all samples*
Liver	0.6	0.3	0.7	0.3	0.5±0.13
Viscera	4.5	1.4	1.3	5.0	3.6±1.15
Ovary	—	4.8	—	—	—
Head	5.7	2.6	4.0	5.1	4.9±0.50
Trunk	27.9	33.8	42.3	25.6	31.9±5.21
Tail	61.3	57.1	51.7	64.0	59.0±3.76

* Excluding Hutt River.

Immature eels 43 in. - 47 in.

Body Tissue	Manawatu River (1943)
Liver	0.7
Viscera	9.5
Head	9.0
Trunk	31.7
Tail	49.1

Maturing eels 48 in. - 52 in.

Body Tissue	Foxton Lakes (1943)	Lake Ellesmere (1944)
Liver	1.4	0.3
Viscera	0.5	3.0
Ovary	14.6	8.2
Head	3.4	4.5
Trunk	35.7	30.1
Tail	44.4	53.9

Migrant eels. Lake Ellesmere, 1942.

	Liver	Viscera	Ovary	Head	Trunk	Tail
A.V.	1.0	1.6	19.3	4.2	32.9	41.0
S.E.	0.18	0.24	1.10	0.26	1.12	0.82

GRANITIZATION IN NEW ZEALAND

PART I. THE EMPLACEMENT OF THE BLUFF NORITE: A REINTERPRETATION

By J. J. REED, Petrologist, New Zealand Geological Survey

(*Received for publication, 6th May, 1948*)

Summary

The field relationships and chemical data obtained by H. Service (1937) in his investigation of the rocks in the Bluff district have been re-examined in the light of the granitization theories propounded by H. H. Read, D. L. Reynolds, H. G. Backlund, A. Holmes and J. A. Dunn. The progressive metamorphism displayed by the rocks is shown to involve metasomatic transformations characterized by increasing basification and dependent on ionic migrations in the solid (or semi-solid) state. The Bluff district can, therefore, be divided by a line, running approximately north-west from the Foreshore and perpendicular to the direction of increasing metamorphism, into two areas, the south-west region of which is the metasomatized (basified) product of the north-east. The basified rocks—norites, hornfelses, granulites, hornblende schists, amphibolites, pyroxenites and peridotites, represent a basic Ca-Fe-Mg front formed by the introduction of the ions of Ca,Fe,Mg,Si, Al,K,Ti,P,Mn; these ions are believed to have been expelled from rocks undergoing granitization on Ruapuke and Stewart islands. The influx of these constituents drove ahead a Na-Ca-Al front responsible for the spilitic character of the Greenhills tuffaceous rocks and for the comparable enrichment in soda shown by the igneous rocks on Tewaewae Point. A secondary basic front possibly advanced ahead of this Na-Ca-Al front. The unaltered rocks in the Bluff district are considered to have been well-bedded basic tuffs with intercalated basalt flows and minor intrusions of gabbro, dolerite, porphyry and quartz porphyry, belonging to the late Palaeozoic (Permian ?) Te Anau Series. The date of metasomatism of this series is probably included in the European Variscan (Hercynian) period.

INTRODUCTION

IN the course of applying to New Zealand geology the granitization theories propounded by H. H. Read (1940, 1943, 1944, 1945), D. L. Reynolds (1944, 1946, 1947a, 1947b), H. G. Backlund (1946), A. Holmes (1945), and J. A. Dunn (1942), the writer had occasion to re-examine the abundant field and chemical data obtained by H. Service (1937) for the intrusion of the Bluff norite. The results of this re-examination with tentative conclusions are given in this paper which it is hoped will stimulate further detailed investigations in the Bluff district, particularly the strict correlation between field observations and chemical analyses by which means alone the geological history of the rocks can be solved.

DISTRIBUTION OF ROCK TYPES

The distribution of rock types in the Bluff district is shown in Fig. 1, redrawn (without alteration) from H. Services' map, and it will be seen that the rocks were grouped into (a) the intrusive series, and (b) the late Palaeozoic (Permian ?) Te Anau Series. Included in the intrusive series are norite, pyroxenite, peridotite, quartz-diorite, and biotite-muscovite granite, but of these only norite has attained wide areal extent and stretches from Bluff Hill to the north of New River. Pyroxenite and partially serpentinized peridotite occur in small isolated outcrops (Fig. 1) whose relation to the norite is obscured by intervening covering sand dunes (Service, *op. cit.*, p. 207). Numerous thin veins

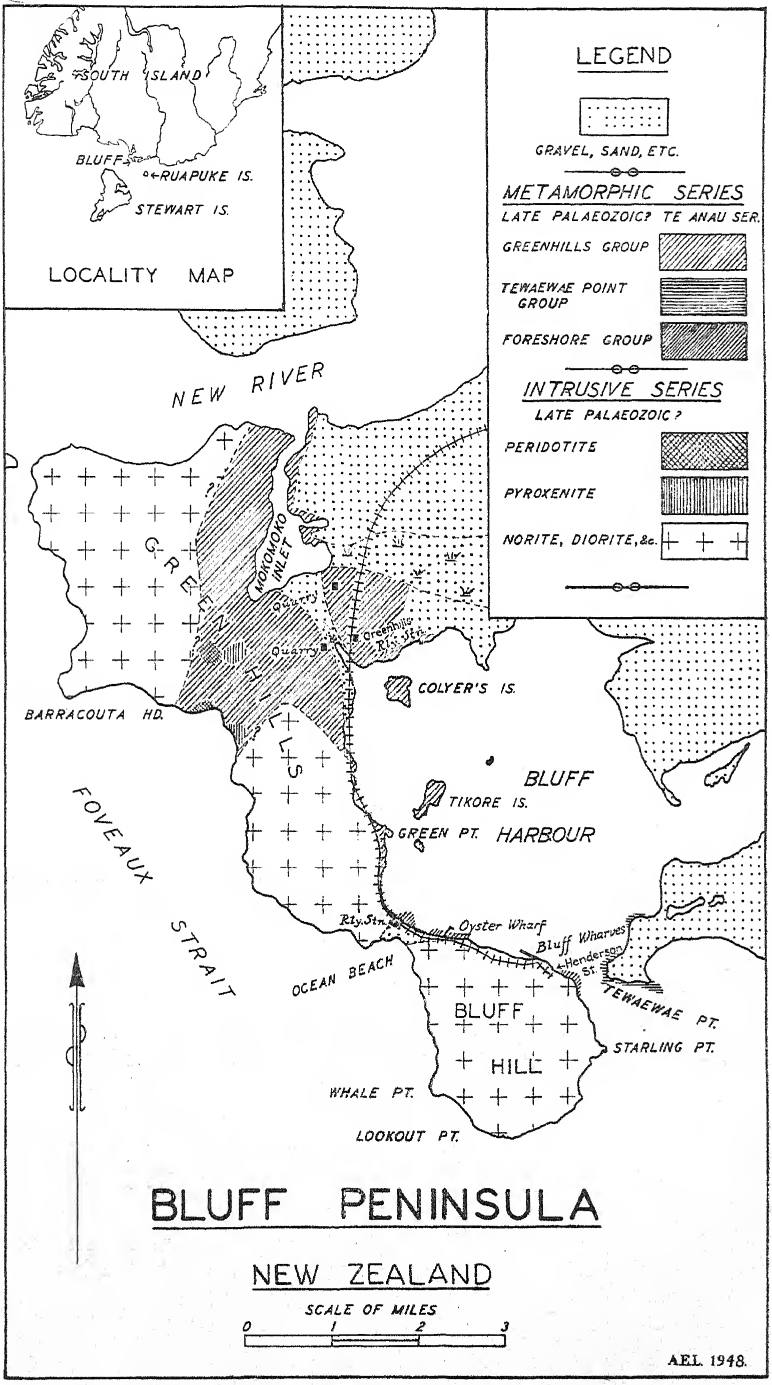


FIG. 1.—H. Service's (1937) geological map of the Bluff district (redrawn without alteration).

of quartz diorites intersect gneissic norite one mile south-west of Starling Point while circular patches invade massive norite on the harbour front half way between the wharves and Ocean Beach railway station (*loc. cit.*, p. 208). Finally, a dyke of biotite-muscovite granite cuts norite on the coast line two miles north-west from Ocean Beach (*loc. cit.*, p. 208).

The Te Anau metamorphic series comprises basic and semi-basic tuffs with dominant spilitic affinities, intrusive rocks and a few true lavas. These are developed in three chief localities—Greenhills, Tewaewae Point and the Foreshore*. The Greenhills group mainly consists of well bedded spilitic tuffs with a general north-west strike and steep dip to the north-east, the dip increasing steadily towards the south-west. The grade of metamorphism also increases from the north-east to south-west. Thus the least altered rocks from north of Mokomoko Inlet contain abundant fragments of the original constituents whereas the corresponding rocks from the Greenhills quarries have lost almost all trace of these ; further westward along the road from the Greenhills railway station, fine grained andesine-actinolite hornfels are found (*loc. cit.*, p. 188). On the sea coast west and north-west of the tuffs, well bedded high-grade granulites are exposed and since they possess the same general dip and strike are assumed to belong to the same metamorphic series although little is known of the rocks occupying the area between them (*loc. cit.*, p. 188). The mineral assemblages in the granulites are pyroxene-hornblende-biotite-albite associated with garnet-calcite-pyroxene-albite, and hornblende-pyroxene-oligoclase-garnet. In one area the granulites are cut by a hornblende-plagioclase-biotite schist (*loc. cit.*, p. 196). The only other rock type in the Greenhills group is an oligoclase trachybasalt which intersects the bedded tuffs at the eastern side of the mouth of Mokomoko Inlet.

The Tewaewae Point group, exposed along the shore for a distance of about one mile, contains seven distinct rock types—epidiorite, albite metadolerite, quartz-keratophyre, keratophyre, keratophyre(?), garnet-bearing quartz keratophyre, albite-actinolite schist, and metabasalt. Of these, massive epidiorite, albitic meta-dolerite and to a less extent quartz keratophyre, are the dominant rock types (Service, *loc. cit.*, Text fig. 1 and p. 205). The presence of a small patch of biotite muscovite granite invading epidiorite 100 yards east-south-east of Tewaewae Point was also noted (p. 208).

The Foreshore group is a strongly banded series of dark green schists and hornfelses striking about 15° west of north and dipping southwards at angles between 78° and 90°. The banding is due to alternation of dark green hornblende-andesine rocks and minor hornblende-pyroxene bands, with lighter coloured, hornblende-oligoclase schists. In three places, respectively 500, 550 and 700 yards south-east of Henderson Street, are outcrops of fine-grained acid granulites which consist essentially of crystalloblastic aggregates of quartz and alkali felspar (*loc. cit.*, p. 203). In the first and third localities, the granulites appear to be bedded among the green schists, but in the second a lenticular patch of granulite cuts obliquely across the foliation planes of a hornblende biotite schist (*loc. cit.*, p. 190). At intervals along the foreshore and forming dykes cutting both hornblende schists and acid granulites are coarse grained amphibolites which petrographic study suggests were originally dolerites (*loc. cit.*, p. 190).

* The Foreshore was defined by Service (*loc. cit.*, p. 187) as that portion of the western shore of the harbour extending for a quarter of a mile to the south-east from the foot of Henderson Street.

METASOMATIC CHANGES DURING METAMORPHISM

The main conclusion reached by Service was that metamorphism of the Te Anau Series resulted from the intrusion of a magmatic Bluff norite. Thus, the Greenhills rock series, spilitic tuff - hornfels-granulite, was considered to be a thermal contact metamorphic series increasing in grade as the Bluff norite was approached. Similarly, the well banded schists and hornfelses exposed on the foreshore represented the thermal metamorphic products of the Tewaewae Point igneous group, the banding being formed by a process of metamorphic differentiation (*op. cit.*, p. 205).

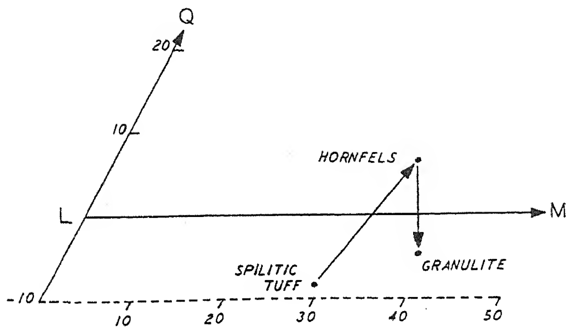


FIG. 2.—Von Wolff diagram depicting the increasing basification in the Greenhills metamorphic series, spilitic tuff-hornfels-granulite. L = felspars, M = saturated melanocrats, Q = quartz.

The Greenhills group will be considered first. Here, the field evidence clearly indicates that the metamorphic changes are from spilitic tuff, through hornblende-andesine hornfels to pyroxene granulite. The chemical relationships involved in this series can be obtained by examination of the three relevant chemical analyses (Nos. 52b, 53, 209, Service, *loc. cit.*, p. 215). For comparison purposes, the analyses have been plotted on a von Wolff diagram (Johannsen, 1939, p. 109) which is highly suitable since on the one hand it separates quartzose, felspathic and melanocratic types from one another and on the other hand it separates chemically oversaturated from chemically undersaturated rocks (Reynolds, 1944, p. 237 ; 1946, p. 393). From Fig. 2, it will be seen that the main change involved in the series is one of increasing basification (Reynolds, 1946, p. 391). How this basification is brought about is revealed by comparison of the weight percentages (Table I), which indicate that in the alteration of spilitic tuff to hornblende-andesine hornfels, Fe,Mg,Si,K,Ti,P, and Mn are added and Na,Ca,Al subtracted. In the second progressive change, hornfels to granulite, Fe,Mg,Si,K,Ti,P are lost and Ca,Na,Al gained, with no change in Mn. Further, it will be noted that the materials lost in the second stage are equivalent to those added in the first change. Examination of the chemical data therefore proves that metamorphism of the original tuffaceous rocks has not been a mineral recrystallization without change in bulk chemical composition, but a metasomatic change involving introduction and migration of certain constituents.

In the second area where increasing metamorphism can be observed. Tewaewae Point-Foreshore-Bluff Hill, Service (1937) accepted a magmatic intrusive origin for the norite and considered the banded

Foreshore schists to result from the contact thermal metamorphism of the generally massive Tewaewae Point igneous group. Since 1937, however, another alternative is possible, *viz.*, that the norite is non-magmatic and is itself a product of metamorphism. As the metamorphism in the Greenhills district has been shown to be one of metasomatism (basification) it is of vital importance to compare the chemical compositions of the epidiorite on Tewaewae Point with the Bluff Hill norite, for both these rocks have similar texture. From the von Wolff diagram (Fig. 3), the conversion of epidiorite to norite is seen to be one of basification and this involves the influx of Fe,Mg,Si,K,Ti,P and Mn, and the departure of Na,Ca,Al (Table II). The transformation of epidiorite to norite, therefore, compares exactly with metamorphism of spilitic tuff to hornfels in the Greenhills district. There is also evidence that a second, more south-westerly, metasomatism is present in the Bluff Hill region for olivine norite has been described from the sea coast one

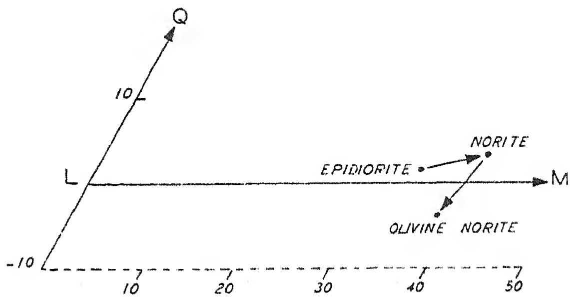


FIG. 3.—Von Wolff diagram showing the basification change of the Tewaewae Point epidiorite to norite and the second desilication change to olivine norite.

mile south-west of Starling Point, and a comparison of the relevant chemical date (Fig. 3, Table II) indicates that the change is one of desilication brought about by the introduction of Ca,Mg,Al,P and the migration of Fe,Si,K,Na,Ti and Mn. This change is similar to the metamorphism of hornfels to granulite in the Greenhills district since both are desilications characterized largely by the introduction of Ca and Al. In the granulite, however, Na is also important whereas Mg accompanies the Ca in the olivine norite.

To summarize, the conversion of epidiorite to norite in the Tewaewae Point-Bluff Hill region compares exactly with the metasomatic changes involved in the metamorphism of spilitic tuff to hornfels in the Greenhills district. Further, a second more westerly desilication, resulting from the influx of Ca,Al (and Mg or Na) is present in both areas. In other words, the Bluff district can be divided by a line running approximately north-west from the Foreshore and perpendicular to the direction of increasing metamorphism into two areas, the south-west area of which is the metasomatised (basified) product of the North-east. The principal active agents in this basification are Fe,Mg,Ca,Si,Al, with enrichment in Ca following a dominantly Fe,Mg phase. In modern nomenclature, the norites, hornfelses and granulites are *diabrochites* as distinct from migmatites, where the metasomatism is one of granitization (Dunn, 1942, p. 234).

MECHANISM OF METASOMATISM AND ESTIMATED VOLUME CHANGES

It is now considered probable that metasomatism in solid (and semi-solid) rocks is effected by processes of ionic diffusion dependent largely on migrations of cations (see Reynolds, 1947, p. 220; Barth, 1947, p. 57). The importance of oxygen in these processes has been stressed by T. F. W. Barth (1947, p. 56; 1948a; 1948b) for among the constituent atoms (ions) of rocks, oxygen takes up the largest volume, the atoms of the other rock building elements—present as cations in the crystal lattice of the silicate minerals—being generally much smaller (Barth, 1948a, Table I). Thus, in the average igneous rock, oxygen, although less than 50 per cent. by weight makes up almost 92 per cent. of the volume (Barth, *loc. cit.*). The accumulation of this large structure of oxygens is made possible by the bonds of the interstitial cations whose electrical charges keep the whole structure together but whose space requirement is negligible. If the volume of any given rock containing 160 oxygens is considered, it is found that very nearly 100 cations are associated with this volume which Barth (1947, p. 56) defined as the *standard cell* of the rock. This does not mean that the volume of the standard cell is the same for all rocks for this varies with the packing of the oxygens. In all rocks, however, belonging to the same or related mineral facies, the standard cell has a rather constant volume (Barth, 1947, p. 56). If we assume that in metasomatic processes the large oxygen ions are stationary (Barth, 1948b, p. 50), it follows that the cations may be replaced and a new rock developed by exchange of but a few per cent. of volume of the rock substance (Barth, 1947, p. 57; 1948b, p. 56).

Calculation of the standard cells of the rocks in the Greenhills and Tewaewae Point-Bluff Hill metasomatic series (Tables III and IV) indicates that the volume changes are very small, varying from ½ to 1½ per cent. Further, since approximately equal volumes of the rocks are being considered, examination of the standard cells gives a clearer picture of the metasomatic migrations than comparison of the weight percentages (Tables I and II), although the overall changes are the same in both. Thus, if the oxygens and hydroxyls are disregarded, the rock transformations in the Greenhills series can be written.

102.57 tuff + (1.18 Fe + 1.76 Mg + 1.30 Si + 0.76 K + 0.51 P + 0.45 Ti + 0.03 Mn + 1.33 H)
− (5.99 Na + 0.44 Ca + 2.94 Al)
= 99.24 hornfels.

99.24 hornfels + (2.96 Ca + 3.32 Na + 0.22 Al + 4.93 H)
− (1.39 Fe + 0.80 Mg + 2.16 Si + 0.63 K + 0.17 P + 0.09 Ti)
= 100.09 granulite.

Similarly for the Tewaewae Point-Bluff area :—

100.34 epidiorite + (1.29 Fe + 0.46 Mg + 0.74 Si + 0.58 K + 0.44 P + 0.83 Ti + 0.07 Mn)
− (0.25 Na + 0.74 Ca + 3.23 Al + 1.27 H)
= 100.53 norite.

100.53 norite + (7.30 Ca + 1.47 Mg + 9.39 Al + 0.28 P)
− (3.69 Fe + 4.73 Na + 7.58 Si + 1.09 K + 0.80 Ti + 0.11 Mn + 0.16 H)
= 100.97 olivine norite.

These changes can be summarized as follows :—

A. Greenhills :

Spilitic tuff + (Fe, Mg, Si, K, P, Ti, Mn) — (Na, Ca, Al) = hornfels.
Hornfels + (Ca, Na, Al) — (Fe, Mg, Si, K, P, Ti, Mn) = Granulite.

B. Tewaewae Point-Bluff Hill :

Epidiorite + (Fe, Mg, Si, K, P, Ti, Mn) — (Na, Ca, Al) = Norite.
Norite + (Ca, Mg, Al, P) — (Fe, Na, Si, K, Ti, Mn) = olivine norite.

CHANGES IN OTHER ROCK TYPES

The greater part of this paper has dealt with metasomatic changes in the two major series, but there still remains other rock types to be considered, e.g., hornblende schists, acid granulites, albite metadolerites, amphibolites, quartz keratophyres, pegmatitic hornblende norites, pyroxenites and serpentinized peridotites. The following tentative conclusions, to be confirmed by further detailed investigations, are offered concerning these rocks.

(a) The well-banded Foreshore schists and hornfelses are probably the metasomatic (basified) product of bedded tuffaceous rocks, for if the original rock is assumed to have the composition of the Greenhills tuffs, examination of the chemical data indicates that the average schist or hornfels is basified compared with the tuff (Fig. 4). On this interpretation the Foreshore schists and hornfelses have been formed in a similar manner to the Greenhills hornfelses.

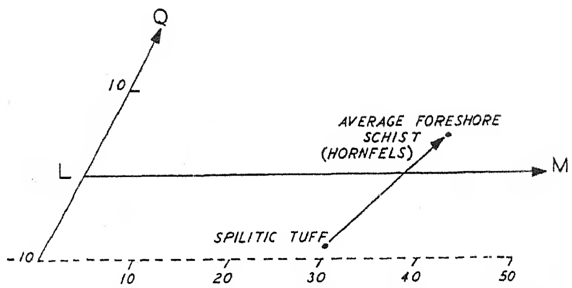


FIG. 4.—Comparison of the Greenhills spilitic tuff with the average Foreshore schist or hornfels on a von Wolff diagram indicates that the transformation is a basification change comparable with the metamorphism of tuff to hornfels in the Greenhills district. (cf. Fig. 2).

(b) The acid granulites exposed on the Foreshore were considered by Service (1937, p. 205) to result from metamorphism of the Tewaewae Point quartz-keratophyres. Comparison of the chemical analysis (Fig. 5) reveals that the change involved is one of desilication (felspathization) dependent on the introduction of K,Al,Si and P. This alteration appears consistent with the basification changes noted in the tuffs and epidiorites for D. L. Reynolds (1946, p. 392, p. 413) has shown that the comparable stage in the transformation of psammitic rocks is one of felspathization.

(c) It is not clear what are the metasomatic products of the Tewaewae Point albite metadolerites, but possibly thay are the amphibolites forming dykes cutting the Foreshore schists, for petrographic study indicates that these are altered dolerites (Service *op. cit.*, p. 204). The chemical composition of the amphibolites is not known.

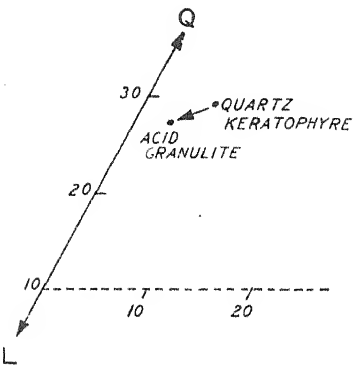


FIG. 5. Von Wolff diagram revealing that the metamorphism of the Tewaewae Point quartz keratophyre to the Foreshore acid granulite is a desilication change brought about by felspathization.

(d) No chemical data is available for the pyroxenites and partially serpentinized peridotites, but it is significant that they outcrop in the basification zone where pyroxene and olivine are known to have formed. It is probable, therefore, that the pyroxenites and peridotites are the product of Ca-Mg-Fe metasomatism of pre-existing basic rocks. In this connection, the evidence obtained from the Newry complex and Malvern area is pertinent for in both these regions biotite pyroxenites have developed by basification, in the first area from pelitic and semi-pelitic rocks (Reynolds, 1944) and in the second from epidiorites (Brammall, 1944).

(e) Besides the typical medium grained norites, two other varieties are known, one a richly hornblendic, coarse pegmatitic rock occuring as small nodules and veins in the main type and the other a strongly gneissic, dense black, fine-grained variety forming veins and dykes intersecting the main mass (Service, *op. cit.*, pp. 207, 208). The field occurrence of the pegmatitic, hornblendic norite suggests that it represents the consolidated equivalent of the migrating basification phase, the principal active agents of which are known to be the ions of Ca,Fe, Mg,Si,Al. This hypothesis is analogous to Barth's interpretation of pegmatites in Iveland-Evje (Norway) as being the consolidated equivalent of the migrating *granitization* phase, the active agents of which were ions of the alkali metals, Al and Si (Barth, 1947, p. 66). The origin of the dykes and veins of fine-grained norite, which in modern nomenclature represent rheomorphic or mobile material, is probably closely allied to that of the pegmatitic norite.

ORIGIN OF THE BASIC FRONT

Re-examination of the rocks in the Bluff district has revealed that the norites, hornfelses, granulites, hornblende schists, amphibolites and probably the pyroxenites and peridotites are diabrochites representing

a Ca-Fe-Mg *front* (Reynolds, 1947, particularly p. 211), resulting from the introduction of the ions of Ca,Fe,Mg,Si,Al,K,Ti,P and Mn. The spilitic character of the tuffs in the Greenhills district and the comparable enrichment in soda shown by the igneous rocks of Tewaewae Point (albitic felspar, sodic hornblende ; Service, 1937, p. 198) is strong evidence that a Na-Ca-Al front was driven ahead of the Ca-Fe-Mg front. Further, the influx of Na,Ca,Al, appears to have given rise to a secondary basic front for its presence would explain the widespread clouding of the felspar, now being replaced by clear albite, which can be observed in the epidiorites, albite metadolerites, garnetiferous quartz keratophyres and metabasalts on Tewaewae Point (Service, *op. cit.*, pp. 196-200) and in the trachybasalts in the Greenhills district (*loc. cit.*, p. 193). This clouding of the felspar by iron ore dust is now believed to be a criterion of basification (Reynolds, 1946, p. 436). The presence of this secondary basic front is also suggested by the occurrence of pink, manganiferous garnets in the quartz-keratophyres exposed on the most easterly part of Tewaewae Point (Service, *op. cit.*, Text Fig. 1). In this discussion, it is unfortunate that the continuation of the Te Anau

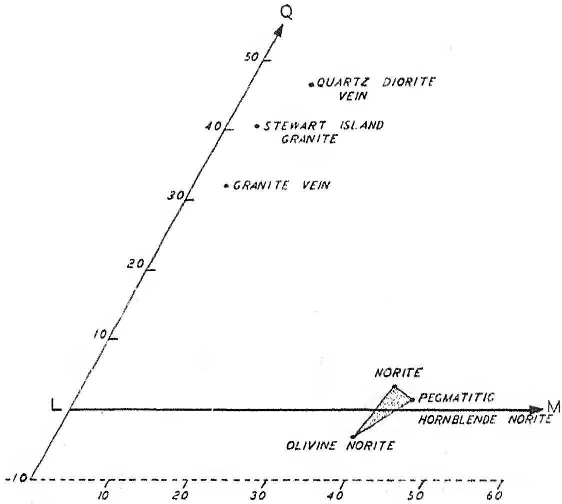


FIG. 6.—Von Wolff diagram comparing the Stewart Island granite with the Bluff norites and veins of quartz diorite and biotite muscovite granite. The quartz diorite analysed is the highly quartzose type. (Service, 1937, p. 213).

series east of Greenhills and Tewaewae Point is covered by sand dunes and that chemical data is lacking for the least altered tuffs outcropping at the mouth of Mokomoko Inlet (Service, *op. cit.*, p. 188). In the light of the evidence of the fronts, however, the writer considers that the unaltered rocks in the Bluff district were well bedded basic tuffs with intercalated basalt flows and minor intrusions of gabbro, dolerite, porphyry and quartz porphyry, i.e., the igneous rocks belong to H. H. Read's volcanic class (Read, 1944, p. 93).

That basification is the complementary process to granitization is now well established (Reynolds, 1946, 1947a, 1947b) and in the Bluff district evidence suggesting an associated granitization phase is given

by the occurrence of quartz-diorite and granite veins. The location of this granitization stage appears to be Ruapuke and Stewart Islands, 13 miles south-east, and 20 miles south-west, respectively, of Bluff (Fig. 1) for there granites, granodiorites, etc., outcrop over wide areas (Service, 1937, p. 214; Williams, 1934, Pl. Xi). The only analyses available concerning these rocks is that of the Stewart Island granite (Williams, *op. cit.*, Table III) which in Fig. 6 is compared with the Bluff norites and veins of quartz diorite and biotite-muscovite granite.

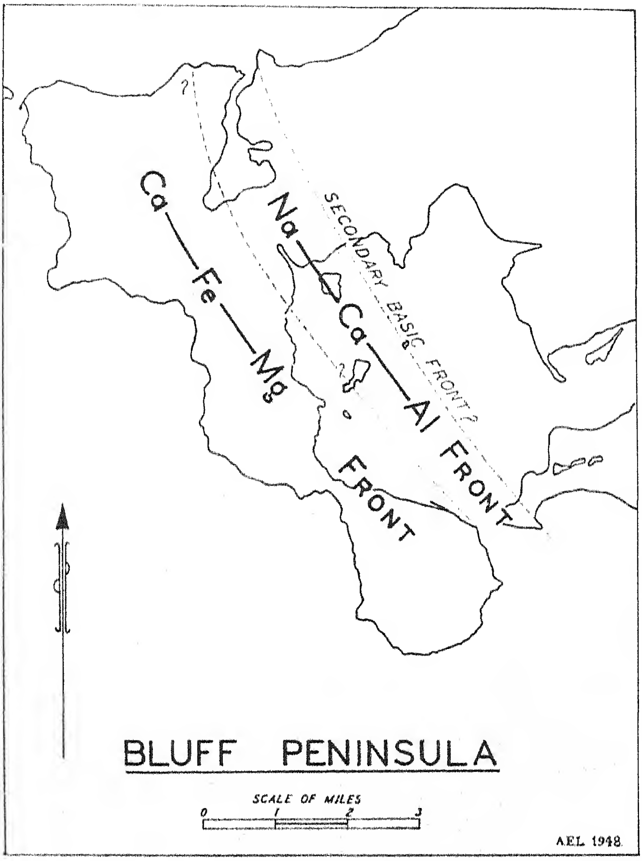


FIG. 7.—Map showing the relationships of the fronts in the Bluff district (Boundaries approximate).

The fronts established in the Bluff district and summarized in Fig. 7 may have regional significance for investigations at present being carried out by the writer suggest that similar rock transformations are reproduced in the metamorphism of the Te Anau series in the Orepuki-Riverton region, and in the Hope-Howard survey districts (Murchison Subdivision). In the Lake Manapouri district too, the rocks described by F. J. Turner (1937) in his eastern Manapouri Province show many affinities with those of Bluff.

DATE OF METASOMATISM

The metasomatic transformations described in this paper have been effected in rocks belonging to the Te Anau series for which a late Palaeozoic (Permian ?) age is most probable, although the only evidence in the Bluff district is the finding of a single " Zaphrentid " coral in the Greenhills spilitic tuff (Service, 1937, pp. 206-7). The upper age limit of metasomatism appears to be provided by the occurrence of spilitic tuffs and keratophyres in Jurassic conglomerates at Nugget Point and Kawhia (Service, *loc. cit.*). The date of metasomatism of the Te Anau series is, therefore, probably included in the European Variscan (Hercynian) period (Umbgrove, 1947, p. 27).

CONCLUSIONS

(1) Re-examination of the field and chemical data indicates that the progressive metamorphic series in the Greenhills district, spilitic tuff->hornfels->granulite, is a metasomatic series characterized by increasing basification. In the alteration of tuff to hornfels, Fe,Mg, Si,K,P,Ti and Mn are added and Na,Ca,Al subtracted, while the second change of hornfels to granulite involves the influx of Ca,Na,Al and removal of Fe,Mg,Si,K,P,Ti and Mn.

(2) In the second area displaying progressive metamorphism, Tewaewae Point-Bluff Hill, the conversion of epidiorite to norite is a basification change exactly comparable with the transformation of spilitic tuff to hornfels in the Greenhills district. A second more south-westerly desilication is also present for the formation of olivine norite south-west of Starling Point involves the introduction of Ca,Mg,Al,P, and expulsion of Fe,Si,K,Na,Ti and Mn.

(3) Correlation of the metasomatic changes in the two metamorphic series indicates that the Bluff district can be divided by a line running approximately north-west from the Foreshore and perpendicular to the direction of increasing metamorphism into two areas, the south-west region of which is the basified product of the north-east.

(4) The metasomatism of the rocks is considered to result from processes of ionic diffusion dependent largely on migrations of cations. The volume changes during metasomatism, estimated by comparison of the " standard cells " of the rocks, are very small, ranging from $\frac{1}{2}$ to $1\frac{1}{2}$ per cent. of the rock substances.

(5) The basified rocks (diabrochites) of the Bluff district—norites, hornfelses, granulites, hornblende schists, amphibolites, pyroxenites, peridotites—are the products of a basic Ca-Fe-Mg front resulting from the introduction of the ions of Ca,Fe,Mg,Si,K,Al,P,Ti,Mn. These ions are believed to have been expelled from the rocks undergoing granitization on Ruapuke and Stewart Islands, 13 miles south-east and 20 miles south-west, respectively, of Bluff. The influx of these basifying constituents led to the formation of a Na-Ca-Al front responsible for the spilitic affinities of the Greenhills tuffs and the comparable enrichment in soda shown by the igneous rocks on Tewaewae Point. A secondary basic front possibly advanced ahead of this Na-Ca-Al front.

(6) The unaltered rocks of the Bluff district are considered to have been well bedded basic tuffs, with intercalated basalt flows and minor intrusions of gabbro, dolerite, porphyry and quartz porphyry, belonging to the Te Anau series for which a late Palaeozoic (Permian ?) age is most probable. The date of metasomatism of this series is probably included in the European Variscan (Hercynian) period.

REFERENCES

BACKLUND, H. G. (1946): The Granitization Problem. *Geol. Mag.*, *83*, 105-17.

BARTH, T. F. W. (1947): The Nickeliferous Iveland-Evje Amphibolite and its Relation. *Norg. Geol. undersok*, *168a*.

——— (1948a): The Distribution of Oxygen in the Lithosphere. *J. Geol.*, *56*, 41-9.

——— (1948b): Oxygen in Rocks: A Basis for Petrographic Calculations. *Ibid*, 50-60.

BRAMMALL, A. (1944): In Discussion of Paper on "The South-western end of the Newry Complex". *Q. J. Geol. Soc.*, *99*, 242-3.

DUNN, J. A. (1942): Granite and Magmation and Metamorphism. *Econ. Geol.*, *37*, 231-8.

HOLMES, A. (1945): Natural History of Granite. *Nature*, *155*, 412-5.

JOHANNSEN, A. (1938): "A Descriptive Petrography of the Igneous Rocks." IV. University of Chicago, Illinois.

READ, H. H. (1940): Metamorphism and Igneous Action. *Brit. Assoc. for the Advancement of Science*, *i*, 223-51.

——— (1943): Meditations on Granite, Part I. *Proc. Geol. Assoc.*, *54*, 64-85.

——— (1944): Meditations on Granite. Part II. *Ibid.*, *55*, 45-93.

——— (1946): This Subject of Granite. *Science Progress*, *34*, 659-69.

REYNOLDS, D. L. (1944): The South-western End of the Newry Igneous Complex. *Q. J. Geol. Soc.*, *99*, 205-40.

——— (1946): The Sequence of Geochemical Changes Leading to Granitization. *Ibid.*, *102*, 389-438.

——— (1947a): The Association of Basic "Fronts" with Granitization. *Science Progress*, *35*, 205-19.

——— (1947b): The Granite Controversy. *Geol. Mag.*, *84*, 209-23.

SERVICE, H. (1937): The Intrusion of Norite and its Accompanying Contact Metamorphism at Bluff, New Zealand. *Trans. Roy. Soc. N.Z.*, *67*, 185-217.

TURNER, F. J. (1937): The Metamorphic and Plutonic Rocks of Lake Manapouri, Fiordland, New Zealand. Part I. *Trans. Roy. Soc. N.Z.*, *67*, 83-100.

UMBGROVE, J. H. F. (1947): "The Pulse of the Earth." 2nd Ed. Nijhoff, The Hague.

WILLIAMS, G. J. (1934): A Granite-Schist Contact in Stewart Island, New Zealand. *Q. J. Geol. Soc.*, *90*, 322-53.

TABLE I.

Chemical relationships in the Greenhills metamorphic series, spilitic tuff-hornfels-granulite, calculated from comparison of the weight percentages.

Rock Change	SiO_2	Al_2O_3	FeO*	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO
	+	−	+	+	−	−	+	+	+	+
Spilitic tuff-> hornfels	2.16	2.39	1.63	1.31	0.36	3.20	0.65	0.65	0.18	0.04
	−	+	−		+	+	−	−		
Hornfels-> granulite	2.31	0.16	1.76	0.59	2.96	1.82	0.53	0.13	0.21	0.00

Tuff + (Fe Mg Si K Ti P Mn) − (Na Ca Al) = Hornfels.
Hornfels + (Ca Na Al) − (Fe Mg Si K T P) = Granulite.
* Total iron as FeO.

TABLE II.

Chemical relationships of the epidiorites, norites, and olivine norites in the Tewaewae Point-Bluff Hill region calculated from comparison of the weight percentages.

Rock Change	SiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO
	+	−	+	+	−	−	+	+	+	+
Epidiorite-> norite	0.53	2.94	1.58	0.29	0.76	0.16	0.44	1.15	0.52	0.10
	−	+	−	+	+				+	
Norite-> Olivine norite	7.03	8.73	4.48	1.14	7.38	2.50	0.86	1.14	0.38	0.14

Epidiorite + (Fe,Mg,Si,K,Ti,P,Mn) − (Na,Ca,Al) = Norite.
Norite + (Ca,Mg,Al,P) − (Fe,Na,Si,K,Ti,Mn) = Olivine norite.

TABLE III.

Chemical and volume changes calculated from standard cells of the rocks for the Greenhills Metamorphic Series.

A. Tuff-hornfels :

Tuff: $H_{4\cdot55}$ $K_{0\cdot92}$ $Na_{12\cdot08}$ $Ca_{6\cdot64}$ $Mg_{4\cdot97}$ $Fe_{5\cdot86}$ $Al_{20\cdot83}$ $Si_{50\cdot70}$ $Ti_{0\cdot32}$ $P_{0\cdot14}$ $Mn_{0\cdot11}$ O_{160}

Hornfels: $H_{5\cdot88}$ $K_{1\cdot68}$ $Na_{6\cdot09}$ $Ca_{6\cdot20}$ $Mg_{6\cdot73}$ $Fe_{7\cdot04}$ $Al_{17\cdot89}$ $Si_{52\cdot00}$ $Ti_{0\cdot77}$ $P_{0\cdot28}$ $Mn_{0\cdot14}$ O_{160}

Additions	Subtractions
1.33 ions H	5.99 ions Na
0.76 ,, K	0.44 ,, Ca
1.76 ,, Mg	2.94 ,, Al
1.18 ,, Fe	
1.30 ,, Si	9.37 cations
0.45 ,, Ti	
0.14 ,, P	Representing 16 valencies
0.03 ,, Mn	

Total 6.95 cations representing 16 valencies

Volume change < ½ per cent.

B. Hornfels-Granulite :

Hornfels : $H_{5\cdot88}\ K_{1\cdot68}\ Na_{6\cdot09}\ Ca_{6\cdot20}\ Mg_{6\cdot73}\ Mn_{0\cdot14}\ Fe_{7\cdot04}\ Al_{17\cdot89}\ Si_{52\cdot00}\ Ti_{0\cdot77}\ P_{0\cdot28}\ O_{160}$

Granulite : $H_{10\cdot81}\ K_{1\cdot05}\ Na_{9\cdot41}\ Ca_{9\cdot16}\ Mg_{5\cdot93}\ Mn_{0\cdot14}\ Fe_{5\cdot65}\ Al_{18\cdot11}\ Si_{49\cdot84}\ Ti_{0\cdot68}\ P_{0\cdot11}\ O_{160}$

	Additions	Subtractions	No change
	4.93 ions H	0.63 ions K	Mn
	3.32 ,, Na	0.80 ,, Mg	
	2.96 ,, Ca	1.39 ,, Fe	
	0.22 ,, Al	2.16 ,, Si	
		0.09 ,, Ti	
Total	11.43 cations	0.17 ,, P	
	representing 15 valencies	5.24 cations	
		representing 15 valencies	

Volume change < ½ per cent.

TABLE IV.

Chemical and volume changes for the series, epidiorite-norite-olivine norite, calculated from standard cells of the rocks.

A. Epidiorite-norite :

Epidorite : $H_{6\cdot04}\ K_{0\cdot58}\ Na_{6\cdot61}\ Ca_{9\cdot99}\ Mg_{6\cdot04}\ Mn_{0\cdot11}\ Fe_{6\cdot69}\ Al_{20\cdot73}\ Si_{48\cdot78}\ Ti_{0\cdot25}\ P_{0\cdot56}\ O_{160}$

Norite : $H_{4\cdot77}\ K_{1\cdot16}\ Na_{6\cdot36}\ Ca_{9\cdot25}\ Mg_{6\cdot50}\ Mn_{0\cdot18}\ Fe_{7\cdot98}\ Al_{17\cdot50}\ Si_{49\cdot52}\ Ti_{1\cdot08}\ P_{1\cdot00}\ O_{160}$

	Additions		Subtractions
	0.58 ions K		1.27 ions H
	0.46 ,, Mg		0.25 ,, Na
	0.07 ,, Mn		0.74 ,, Ca
	1.29 ,, Fe		3.23 ,, Al
	0.74 ,, Si		
	0.83 ,, Ti	Total	5.49 cations
	0.44 ,, P		
			representing 13 valencies
Total	4.41 cations		
	representing 13 valencies		

Volume change < ½ per cent.

B. Norite-olivine norite :

Norite : $H_{4\cdot77}\ K_{1\cdot16}\ Na_{6\cdot36}\ Ca_{9\cdot25}\ Mg_{6\cdot50}\ Mn_{0\cdot18}\ Fe_{7\cdot98}\ Al_{17\cdot50}\ Si_{49\cdot52}\ Ti_{1\cdot08}\ P_{1\cdot00}\ O_{160}$

Olivine norite : $H_{4\cdot61}\ K_{0\cdot07}\ Na_{1\cdot63}\ Ca_{16\cdot55}\ Mg_{7\cdot97}\ Mn_{0\cdot07}\ Fe_{4\cdot29}\ Al_{26\cdot89}\ Si_{41\cdot94}\ Ti_{0\cdot28}\ P_{1\cdot28}\ O_{160}$

Additions		Subtractions
7.30 ions Ca		0.16 ions H
1.47 ,, Mg		1.09 ,, K
9.39 ,, Al		4.73 ,, Na
0.28 ,, P		0.11 ,, Mn
		3.69 ,, Fe
18.44 cations		0.80 ,, Ti
		7.58 ,, Si
representing 47 valencies		
	Total	18.16 cations
		representing 47 valencies

Volume Chance < 1½ per cent.

A BALANCED WATER-FLOW WATTMETER FOR CENTIMETRE WAVELENGTHS

By W. A. PENTON and I. R. A. OVERTON, Dominion Physical Laboratory, Department of Scientific and Industrial Research

(*Received for publication, 5th August, 1947*)

Summary

This paper describes an R.F. Wattmeter of the continuous-flow water type designed and constructed at the Dominion Physical Laboratory for the measurement of mean power of R.F. pulses at 3 cms. wavelength (10,000 megacycles/second). The design provides for equation of the R.F. power to power from the 50-cycle mains supplied from a controllable source, and eliminates most of the sources of error due to heat loss which are commonly met with in other calorimetric methods. The instrument could be easily modified to suit other wavelengths and other R.F. transmission systems.

INTRODUCTION

THE instrument to be described was designed and constructed to meet a laboratory requirement for the accurate measurement of R.F. power at 3 cm. Portability was not a primary requisite.

Methods of calorimetry by absorption of power in a liquid load and measurement of absolute temperature rise resulting, have been widely used in other countries, and generally seem to be recognized as the most accurate method available. The precautions necessary to attain extreme accuracy are, however, very considerable. Loss by heat exchange and heat radiation is obviously likely to occur unless thermal insulation is extremely thorough. Temperature rise must be kept to a minimum, this implying very delicate thermometric measurement if percentage accuracy is to be high. Mechanical stirring must be very thorough before readings are taken, and in general the procedure is long and laborious.

Constant flow methods using thermocouples or resistance thermometers are quicker, but thermocouples, though sensitive, are variable in characteristic and not easily made up into a direct reading instrument of high accuracy. In any case, radiated losses noted above are not eliminated by this method.

The continuous flow method using a separate source of power to balance power absorbed from the R.F. source overcomes most of the difficulties noted above. Heat from a separate controllable source is generated to equal the R.F. heating produced and the point of equal heat observed by a balance indicator. The amount of power required to balance is read directly from a metering system and is equal to the R.F. power absorbed, providing that radiation losses from both power-absorbers are equal and that the heat exchange in the system is negligible. Both these requirements are easily met by correct design of the system.

This is the system used in the instrument to be described. So far as the writers are aware, only brief mention of the system has been made in technical literature, and that in the course of discussion on a recent paper by Clayton *et al.* (1946). No full account has been published, although there is little doubt that the method has actually been used quite widely.

GENERAL DESCRIPTION (See Fig. 1)

A water stream at constant pressure is led through a polystyrene absorbing wedge, a comparison chamber of polystyrene containing a heating element, and polystyrene chambers containing the four arms of a resistance bridge which uses platinum or nickle wire as the heat-sensitive resistance elements.

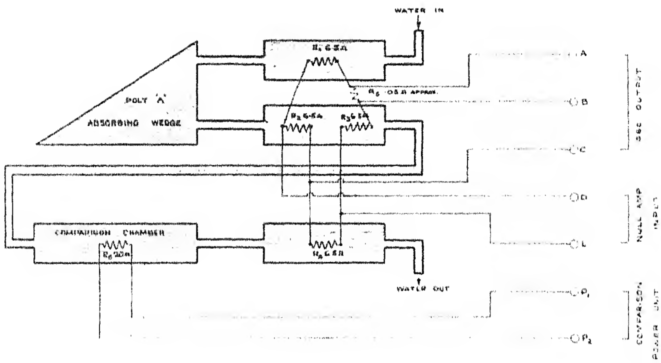


FIG. 1

The bridge is supplied with a source of A.C. power at about 500 cycles from an R.C. oscillator, and bridge output is connected to an amplifier, diode rectifier and meter to record bridge balance.

The resistance in the comparison and balancing chamber can be supplied with 50 cycle A.C. power through a transformer with fine and coarse primary controls, the voltage and current to the resistance being metered with instruments specially checked for accuracy.

In use the bridge is first balanced "cold" and R.F. power is then applied. The bridge unbalances and is rebalanced by introduction of 50 cycle power to the comparison chamber. The power required for rebalance is read from the meters and should equal the R.F. power at all water speeds, within the limits of accuracy of the instrument.

UNITS OF SYSTEM

These are :—

Bridge oscillator and bridge null indicating amplifier. (See Figs. 2, 3 and 4.)
Calorimeter unit. (See Figs. 1, 5 and 6.)
Balancing power unit. (See Figs. 4 and 7.)
Constant head water tank.

(1) *Bridge Oscillator and Bridge Null Indicating Amplifier.*

A 6SJ7 is used as an R.C. oscillator whose frequency is determined by the feedback network between grid and plates. In this case the frequency generated is 530 cycles, chosen as well-removed from power and power harmonic frequencies. The cathode resistor of this tube is critical for the best wave form of oscillator output. The output is amplified by a 6V6 and applied to the bridge through a step-down transformer to match approximately the bridge input resistance.

The grid voltage divider is arranged so that not more than 75 m.a. may be made to flow in the bridge, this corresponding to a dissipation of approximately 40 mw.

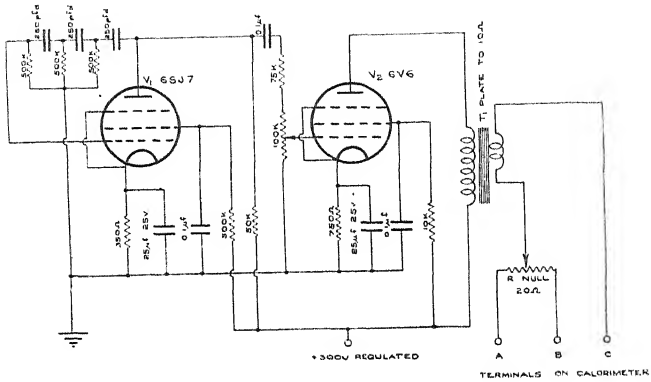


FIG. 2

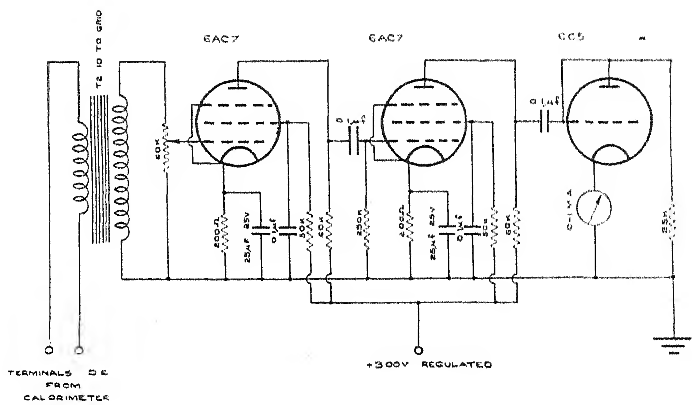


FIG. 3

An input transformer matches the bridge output to the grid input of the 2 stage null indicating amplifier using 6AC7 tubes. Any out-of-balance bridge voltage is thus amplified and rectified by the 6C5 connected as a diode. Rectified current is displayed on M.1. The value of load resistance is selected to limit the current passed by the diode thus protecting the meter from heavy overload. Linearity of meter scale in a null indicating instrument is not of major importance, although as Fig. 8 shows, substantial linearity up to $\frac{1}{5}$ full scale is realized.

The two units described are accommodated in the upper chassis, shown in Fig. 4, together with their common regulated power supply. The upper panel carries all controls, output terminals to calorimeter unit, null indicating meter, and also the voltmeter and ammeter for the balancing power unit.

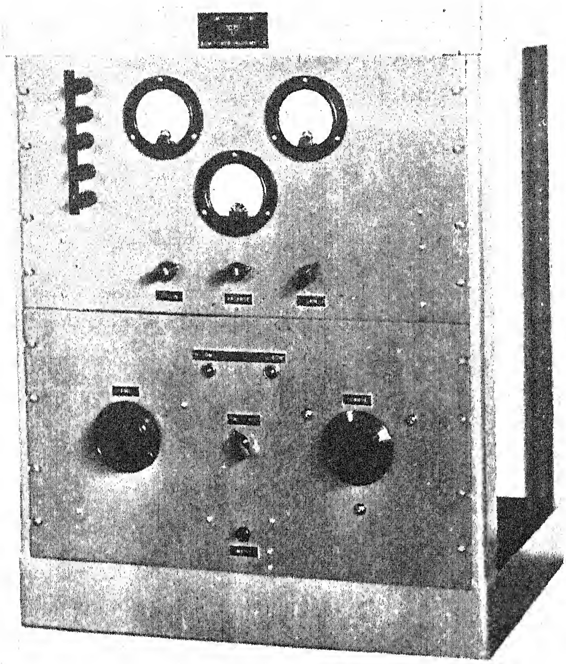
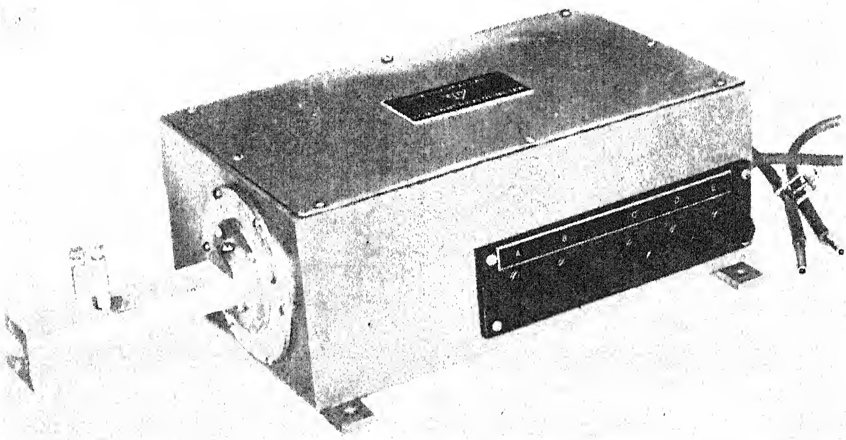


FIG. 4

FIG. 5



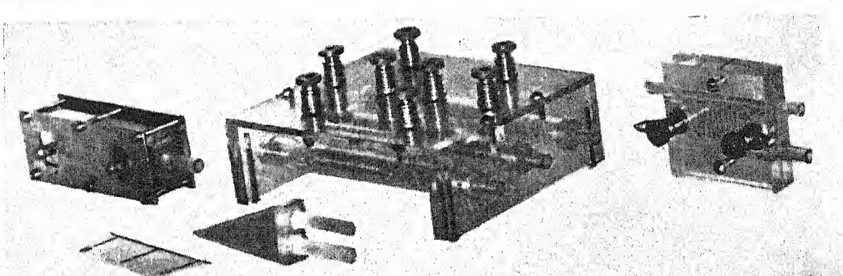


FIG. 6—A. Comparison chamber; B. Absorbing wedge; C. Bridge chamber assembly; D. 11 junction copper-constanton thermo-couple.

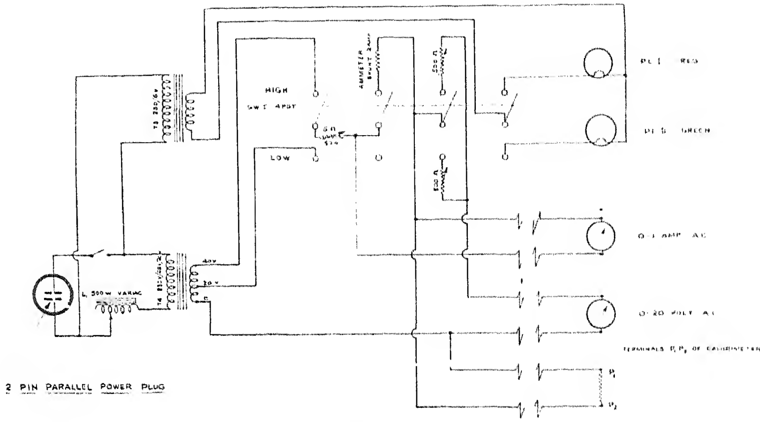


FIG. 7

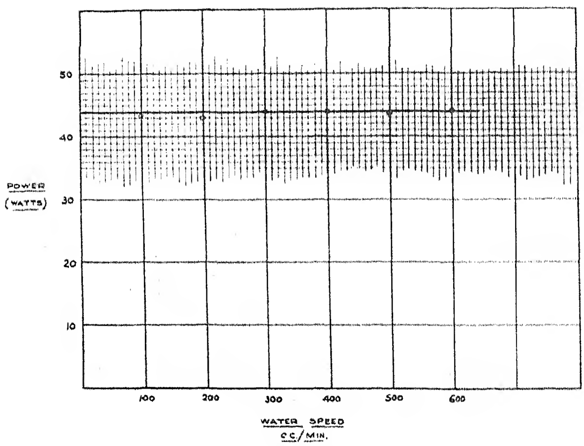


FIG. 8

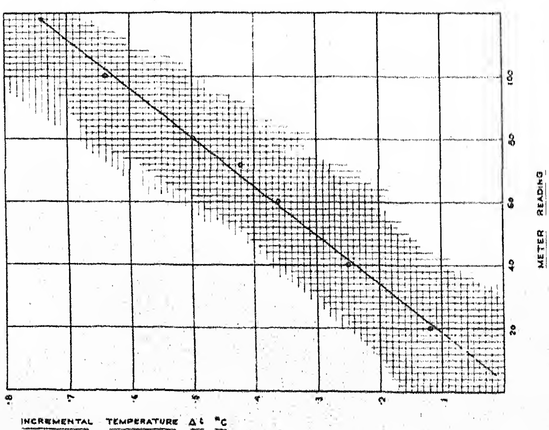


FIG. 9

(2) *Balancing Power Unit. Fig. 4, Lower Panel.*

This unit incorporates :

(a) Step-down transformer 230V/20V/40V with variac control in primary as "coarse" control.
(b) Change-over switch "low-power — high-power" with appropriate indicating lamps.
(c) "Fine" control, being a 5 ohm variable resistance, in series with transformer secondary.
(d) Appropriate meter shunts and series resistors.

Voltmeter (0-20 V.A.C.) and ammeter (0-1 amp A.C.) are situated on panel above.

In "low-power" position S.W.1. applies a maximum of 20 v., across the 20 ohm heating resistance in comparison chamber of the calorimeter unit, and powers up to 20 w. are read. In "high-power" position, R_2 is placed in series with the voltmeter to extend its range to 40 v., and maximum powers up to 80 w. may be read.

The variac L.1. is enclosed in a mu-metal shield to eliminate stray mains frequency pick-up in the indicating amplifier.

(3) *Calorimeter Unit.*

Fig. 5 is an external view of this unit and Fig. 6 shows the various items which are assembled inside the unit, interconnected with rubber gas-tubing. Fig. 1 shows the flow diagram and the bridge arms.

Referring to Fig. 6, the comparison chamber A is milled from polystyrene stock and is approximately $2\frac{1}{2}$ in. long and $\frac{3}{4}$ in. square (inside measurements). The detachable lid is sealed with a gasket and carries the balancing resistor R.6. The resistor is spiral-wound to 20 ohms with approximately 3ft. of 34 g. nichrome on a mica former of cruciform shape, giving good heat exchange between water and wire.

The absorbing wedge, Fig. 6B, is milled from polystyrene in the shape of a pyramid tapering in two dimensions and is $2\frac{1}{2}$ in. long, breadth and width being such as to form a snug fit inside standard 3 cm. waveguide ($\frac{1}{2}$ in. $\times$ 1 in. I.D.) The waveguide itself, shown projecting from unit in Fig. 5 has a "non-metallic" shorting plunger (not shown in Fig.) at the remote end of the polystyrene wedge, the inlet and outlet pipe of which protrude through the shorting plunger into the unit itself.

Matching stubs shown in Fig. 5 were provided on the guide but actually proved unnecessary in operation.

The wedge as described has $\frac{1}{16}$ in. walls and a cubic capacity of approximately 3 cm. Its taper into two planes causes absorption to be gradual and almost complete. Measurements at low power place its efficiency at 98 per cent.

The bridge chamber assembly is shown at Fig. 6C. The four bridge arms, each consist of approximately 34 in. of .005 nickel wire wound helically on the hollow polystyrene tube $\frac{1}{4}$ in. O.D. The $\frac{1}{4}$ in. tube is held inside a $\frac{1}{2}$ in. O.D. polystyrene tube by end spacers and the whole cemented tightly with polystyrene cement. The $\frac{1}{4}$ in. inside tube protrudes $\frac{1}{2}$ in. either end to allow of rubber tube interconnections. Two arms are accommodated on a common tube inside the middle chamber and one arm each in the 2 outer chambers.

All chambers are supported in end-clamps of $\frac{1}{4}$ in. polystyrene with an upper terminal board also of polystyrene the whole forming a rigid assembly. When in use, the assembly is held in 3 deep slots in a block of sponge rubber about 5 in. square, thus heat insulating adjacent chambers and also providing a shock-proof mounting.

A, B and C are all accommodated within the calorimeter unit, which is of sheet steel with lining and partitions of $\frac{1}{2}$ in. sponge rubber.

D shows an 11-junction copper-constanton thermocouple originally built to be installed in the water circuit in addition to A, B and C to give quick direct readings on a galvanometer. However the calorimeter itself has proved so quick-reading that the thermocouple section has not been added.

A design weakness has since been revealed in the calorimeter unit in that the bridge arms of section C are not readily accessible in event of breakage of one of the nickel elements. At a later date this section will be amended so that construction follows in essence that of the comparison chamber A. (See Appendix).

(4) *Constant-Head water tank.*

This is a simple copper tank of capacity about $\frac{3}{4}$ cu. ft. Tap water is introduced through a $\frac{1}{2}$ in. pipe at the bottom and carried off through a $\frac{1}{2}$ in. overflow near the top. The whole assembly mounts 7 or 8 ft. up on the wall above the calorimeter itself. The feed to the calorimeter is taken off in $\frac{3}{16}$ in. I.D. rubber gas tubing, with appropriate adjustable cocks to vary water flow.

WATER FLOW REQUIRED AND FACTORS DECIDING FLOW

In any calorimeter system it is desirable that absolute temperature rise be as small as possible. A rise of one degree is generally considered the maximum desirable.

In this particular system, however, it was felt that since normal heat losses balance out and can be disregarded, a temperature rise of 2° centigrade should not be excessive.

Now,

$$Wt = J \times M \times S \times \Delta T$$

Where W = watts dissipated
t = time in seconds
J = Joules equivalent (=4.19)
S = specific heat of water
ΔT = change in temperature
M = mass of water per second.

From the above equation it is found that if ΔT is to be 2° and W = 80 w. then M = 9.6 g./sec. = 570 ml./min. approximately.

In the design of the instrument, therefore, a speed of at least 600 ml./sec. was aimed at, this being the deciding factor in choice of bore of all tubing in the water circuit and in positioning of constant-pressure tank. The full speed of water flow on "high" power is just 600 ml./sec. hence it is safe to assume that ΔT does not exceed 2°. The powers most commonly required to be measured are in the vicinity of 40 w. and in the region the temperature rise approximates one degree.

On "low" power water speed is dropped to approximately 150 ml./min., which permits the same temperature rise above ambient.

Fig. 8 shows a graph of water speed VS. power recorded at several different speeds. It is seen that the curve is quite flat and that the power extrapolated to infinite speed is the same as that recorded at the higher speeds.

Fig. 9 shows the relation between "null" meter reading and absolute temperature change, recorded with a sensitive Beckmanns thermometer. The indicating system as a whole is responsive to changes of 1/100°, or approximately ½ w. This is a reading accuracy, at usual powers in the 40-50 w. range, of 1 per cent. Actually the overall accuracy of the instrument is dependent mostly upon the accuracy both inherent and reading, of the a.c. ammeter and voltmeter. Experience so far suggests that results can be depended on to better than 5 per cent. at normal power levels, which is quite high accuracy at centimetre wavelengths. Occasional variations in tap-water temperature are shown as a quick fluctuation.

In use, 1 min. is sufficient to reach "cold" equilibrium, about 5-10 sec. for power to be absorbed in the wedge, and up to 1 min. to adjust and read the balancing power, this depending somewhat on the amount of experience the operator has had.

CONCLUSION

This design, which has proved successful at 3 cm., could be suitably adapted for measurement of R.F. power at other frequencies and power levels, and with coaxial as well as wave-guide outputs. In the case of coaxial line outputs a section of the line itself might be used as the load replacing the polystyrene wedge, with a watertight partition of a dielectric, whose dimensions and dielectric constant are such as to cause it to act as a matching transformer between line and water load. Increased powers could be catered for by increased rate of flow through the system. Either C.W. or pulsed power may be measured.

APPENDIX

The work described in this paper was carried out during the latter half of 1946. In the interim, certain amendments have been made to the original equipment, while descriptions of similar equipment have since appeared in other publications, and reference to these sources is now given.

In section (3) above, final paragraph, mention is made of a design weakness due to inaccessibility of bridge arms in the event of a failure. A modified assembly has been tried out, in which the bridge arms are contained in separate chambers milled from polystyrene and following essentially the form of the comparison chamber (Section 3). The nickel elements are wound on a mica former of cruciform shape and supported from the detachable lid, which is sealed with a gasket.

This has improved the instrument considerably from the maintenance aspect. However, there is some loss in sensitivity and speed of reaching equilibrium, due to the greater water-volume of the chamber. Reduction of flow speed is of assistance in overcoming this, and the greater temperature rise does not seem to affect accuracy to any observable degree. It is noticed that overseas workers (Turner (1946), Montgomery *et al.* (1947)) have accepted quite high values of temperature rise, relying on the self-compensating action of this method to nullify the effect of increased radiation losses.

REFERENCES

CLAYTON, R. J. *et al.* (1946): Radio Measurements in the Decimetre and Centimetre Wavebands (Discussion). *J. Inst. Elec. Eng.*, *93*, Part III, 97-125.

MONTGOMERY, D. C. *et al.* (1947): Technique of Microwave Measurements. *Mass. Inst. Tech.*, *Radiation Lab. Series*, *11*, Chap. 3, Sections 3. 34, 3. 35, 194-204.

TURNER, L. B. (1946): Balanced Calorimeters for 3,000 and 10,000 Mc/s. with Tapered Water Loads for H01 Rectangular Pipes, *93*, Part III A, 1767-476.

A NOTE ON THE OCCURRENCE OF COPTOTERMES NYMPHS IN HARDWOODS FROM AUSTRALIA

By K. M. HARROW, Wood Technologist, Plant Diseases Division, Department of Scientific and Industrial Research

(*Received for publication, 26th July, 1947*)

RECENTLY, in a shipment of hardwood from Australia, Mr. A. F. Barnes, Auckland City Termite Inspector, found a post which contained a number of nymphal forms of *Coptotermes acinaciformis* Frog. For some time, nymphs have been considered to be the form in which originators of the established colonies in New Zealand reached this country but although they have very occasionally been found in New Zealand with forage parties some distance from the parent nest (Harrow, 1942), they have not previously been observed among groups of *Coptotermes* which have been arriving in hardwood from Australia. In the past, these have invariably been normal forage parties of workers and soldiers which can not reproduce and therefore do not constitute a danger.

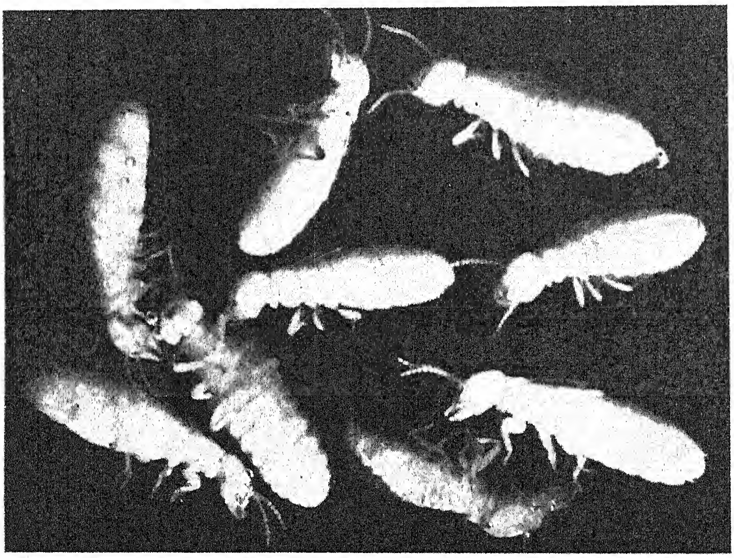


FIG. 1 Nymphs and Soldier of *C. acinaciformis*

In the post found by Mr. Barnes on the "S.S. Fort Pic" (11th April, 1947), however, were nymphs showing well developed wing buds (Fig. 1). On maturity as alates these insects would be capable of setting up new colonies. Nymphs may also become supplementary reproductives without maturing normally (Kelsey, 1945), and in this way enable the group to establish and multiply. It can be seen therefore, that the presence of nymphal forms in imported timber constitutes a definite menace.

REFERENCES

HARROW, K. M. (1942): Preliminary Notes on the Treatment of Australian Subterranean Termites in New Zealand. *N.Z. J. Sci. and Tech*, *24*, (*Sec. B*). 47-52.

KELSEY, J. M. (1945): The Influence of Termite Reproductive Castes on the Colony and on Control Measures. *N.Z. J. Sci. and Tech.*, *26*, (*Sec. B*), 353-9.

OPTICAL PROPERTIES AND CHEMICAL COMPOSITION OF VIVIANITE DEPOSITED ON WOOD

By J. J. REED, New Zealand Geological Survey

(*Received for publication, 2nd December, 1947*)

Summary

The optical properties and chemical composition are given for vivianite (iron phosphate $Fe_3(PO_4)_2.8H_2O$) deposited by secondary solutions on wood.

RECENT studies of vivianite ($Fe_3(PO_4)_2.8H_2O$) and other minerals belonging to the vivianite group (Wolfe, 1940; Barth, 1937; Takane and Omori, 1936) have considerably added to the knowledge of these minerals. The opportunity was therefore welcomed of determining the optical properties and chemical composition of a vivianite specimen forwarded to the Geological Survey Department by Mr. L. D. Caldwell of Ashhurst.

The vivianite in the specimen (P.10631*) is royal blue in colour and occurs both in massive form and in slender prisms up to 1 cm. in length. The prisms possess a vitreous lustre and some occur in a radiating pattern. The vivianite has been deposited upon wood, the structure of which is still visible with a hand lens; the wood is dark brown and almost opaque under the microscope. The source of the iron phosphate solutions forming the vivianite is not known.

* Catalogue number of specimen in the mineral and rock museum of the New Zealand Geological Survey.

TABLE I

Sample	(i)	(ii)
SiO_2	nt. fd.	—
Al_2O_3	nt. fd.	0.31
Fe_2O_3	5.10	4.27
FeO	*35.63	37.20
TiO_2	trace	—
CaO	nt. fd.	0.85
MgO	nt. fd.	0.57
P_2O_5	27.15	27.25
Total H_2O	28.36	27.55
MnO	0.72	—
Organic matter	2.88	1.42 insoluble
	99.84	99.42

* Determined by F. J. Seelye.
(i) Vivianite, Ashhurst. Analyst, T. A. Rafter.
(ii) Vivianite, Moravia (Pelisek, 1935).

The vivianite was separated from the wood by bromoform-benzene mixtures. In Table I, an analysis of the vivianite by Mr. T. A. Rafter is quoted together with an analysis of vivianite from Moravia. It will be noted that the analysis indicates that the vivianite contains 5.10 per cent. ferric oxide. Fresh vivianite is colourless (Dana, 1892, p. 815, and Winchell, 1933, p. 126), the blue colour of most specimens resulting from the oxidation of the iron. From the analysis it may be calculated that 82.93 per cent. of unoxidized vivianite is present, or 84.62 per cent. if the manganese revealed by the analysis is inferred to be an

isomorphous replacement of ferrous iron (Fe^{++}) in the vivianite—a likely possibility in view of the similarity of the ionic radii of the cations Fe^{++} and Mn^{++}. When the blue vivianite is crushed a white or bluish white powder is produced, but this rapidly changes colour to deep blue.

TABLE II

Vivianite	This paper	Wolfe, 1940 ; Larsen and Berman, 1934; Winchell 1933	Dana, 1932	Ulrich, 1925
α	1.581±0.001	1.579	1.580	1.5816
β	1.605±0.001	1.603	1.598	1.6042
γ	1.633±0.001	1.633	1.627	1.6365
$\gamma - \alpha$	0.052	0.054	0.047	0.0549
2 V	85±3 (meas.)	83°		
Optic sign	+	+	+	+
$\gamma \wedge c$	28°	28°	28°	29°
b	×	×	×	×
Dispersion	$r < v$ weak	$r < v$ weak	—	—
Sp. Gr.	2.59	2.676 (Wolfe); 2.6 (Winchell; Larsen and Berman); 2.711 (Calc., Barth, 1937)	2.6	2.678
Cleavages	(010)	(010)	(010)	—
Hardness	2	1.5-2 (Wolfe); 2 (Winchell)	1.5-2	—

The optical properties of the vivianite are tabulated in Table II and for comparison data obtained by other investigators are included. The refractive indices were measured by the immersion method and the values determined with sodium light. The specific gravity was measured by a pycnometer using toluene as the immersion liquid and also by a Berman density micro-balance. The figure obtained in both cases (2.59) although comparable with that quoted by Winchell (1933), Dana (1932) and Larsen and Berman (1934), is lower than the values given by Wolfe (1940), and Ulrich (1925), and considerably lower than the calculated value (2.711) of Barth (1937). This low figure cannot be due to the presence of the Bobierrite molecule ($Mg_3(PO_4)_2.8H_2O$) since the analysis failed to reveal the presence of magnesium, and possibly results from the presence of organic matter (2.88 per cent.).

The vivianite is characterised by strong pleochroism in blue. The pleochroic scheme is given in Table III, where it is compared with the data obtained in earlier studies.

TABLE III

Vivianite	This Paper	Winchell (1933)	Dana (1932)	Ulrich (1925)
X	Deep cobalt blue	Very deep blue	Cobalt blue	Deep blue
Y	Colourless, or pale blue	Nearly colourless	Pale greenish yellow	Pale bluish green
Z	Colourless, or pale brown	Very pale olive green or brownish	Pale greenish yellow	Pale yellowish green
Absorption	X > Y = Z			

REFERENCES

BARTH, T. F. W. (1937): Crystallographic Studies in the Vivianite Group. *Am. Min.*, *22*, 325-341.

DANA, E. S. (1892): "The System of Mineralogy of J. D. Dana." 6th edition. J. Wiley and Sons, New York.

DANA, E. S. and FORD, W. E. (1932): "A Textbook of Mineralogy." 4th edition. John Wiley and Sons, New York.

LARSEN, E. S. and BERMAN, H. (1934): The Microscopic Determination of the Nonopaque Minerals. *U.S. Geol. Surv. Bull.* 679.

PELISEK, J. (1935): Vivianite from the Forest Soils of Adamov, Moravia. *Priroda, Mor. Ostrava*, 28, 279-281. (*Mineral Abst.*, 6, 357.)

TAKANE, K. and OMORI, K. (1936): Crystal Structure of Vivianite from Ashio Mine, Japan. *J. Jap. Assoc. Min. Petr. Econ. Geol.*, 16, 234-40, 263-76. (*Mineral Abst.*, 7, 90.)

ULRICH, F. (1925): Crystallography of Vivianite from Rodna Vecche. *Rozpravy Ceske Akad.*, 23, No. 33. (*Mineral Abst.*, 3, 49-50.)

WINCHELL, A. N. (1933): "Elements of Optical Mineralogy." 3rd edition. John Wiley and Sons, New York.

WOLFE, C. E. (1940): Classification of minerals of the type $A_3(XO_4)_2.nH_2O$ (concluded). *Am. Min.*, 25, 787-809.

APPENDIX

DESCRIPTION OF CHEMICAL ANALYSIS

By T. A. RAFTER, Chemist, Dominion Laboratory, Department of Scientific and Industrial Research

THE presence of organic matter in the sample as sent in for analysis complicated the procedure adopted.

ESTIMATION OF ORGANIC MATTER

To a weighed 30 ml. platinum basin plus platinum stick was added 0.5 g. of sample. The vivianite readily dissolved on warming with 20 ml. of 1:3 HCl, leaving the organic matter. The soluble portion was removed by applying gentle suction to the filtered stick and the residue thoroughly washed with warm water. A further treatment of the residue with 10 ml. of acid to remove possible traces of vivianite was carried out. The final residue was dried to constant weight at 105°C. Weight of residue from 0.5 g. amounted to 0.0164 g. After ignition a small residue 0.0020 g. consisting largely of iron oxide remained which on solution in HCl was added to the main solution. The sample contained, therefore, 2.88 per cent. organic matter.

ANALYSIS OF ORGANIC MATTER

A further 1 g. sample was taken and treated as above, but after obtaining the weight of the organic matter it was carefully brushed into a small weighed platinum boat, and the boat reweighed. By combustion in oxygen and absorption of the carbon dioxide and water formed, it was found that the 2.88 per cent. organic matter was equivalent to 1.46 per cent. oxygen and 1.42 per cent. of water.

THE SOLUBLE PORTION

As the ratio of iron to phosphate in the solution was unknown, a solution containing approximately 20 mg. of Fe_2O_3 was added, so that there would be sufficient iron present to precipitate all the phosphate by ammonia and so avoid contamination of the R_2O_3 precipitate by lime and magnesia. The same volume of iron solution was added to the blank to enable the necessary deduction to be made.

ANALYSIS

To the blank and the HCl solution obtained as above 5 mls. of conc. HNO_3 were added and the solution evaporated down in a covered 100 ml. beaker, to ensure complete oxidation of the iron to the ferric state. After dilution the usual procedure as for rock analysis was carried out for the R_2O_3 — group + silica if present, removal of manganese by bromine water, and an examination for the presence of lime and magnesia.

FERROUS IRON, MANGANESE AND PHOSPHATE

Were determined on separate portions of the sample by the conventional methods.

WATER ESTIMATION

(a) *Water Minus.*

One gram of the sample was dried to constant weight at 105°c. Four one hour periods were required before constant weight could be determined.

(b) *Water Plus.*

An attempt was made to obtain this figure by ignition in a well covered crucible at temperatures up to 500°c., but owing to the change in colour of the residue indicating oxidation and the uncertain behaviour of the organic matter also present, this method was abandoned.

(c) *Total Water.*

This was determined by combustion in oxygen and absorption of the CO_2 and H_2O formed, in solid reagents as is the usual practice in the determination of carbon and hydrogen in organic matter. By this method 29.78 per cent. of water was formed, from which had to be deducted the water formed from the organic matter present, i.e., 1.42 per cent., leaving a total water percentage of 28.36 per cent.

THE NEW ZEALAND

JOURNAL OF SCIENCE

AND

TECHNOLOGY

Editor: D. Cairns, M.Sc. (Assistant Editor: M. O'Connor, M.Sc.) Department of Scientific and Industrial Research, Wellington

VOL. 29. SEC. B MARCH, 1948 NUMBER 5

PRELIMINARY REPORT ON THE LIGNITE DEPOSITS OF THE MATAURA VALLEY, EASTERN SOUTHLAND COALFIELD

By R. W. WILLETT, New Zealand Geological Survey, Department of Scientific and Industrial Research

(*Received for publication, 9th June, 1947*)

Summary

A description of the topographic and geologic conditions of the Mataura Valley lignite deposits is presented. The area discussed extends from Gore south to the coast, and west as far as Makarewa River, and is bounded in the east by Mataura River. It lies within the Provisional One Mile sheets S/169, S/170, S/177, S/178, S/182, and S/183, over the following survey districts in the Southland land district: Waimumu, Lindhurst, Lothian, Mataura, Tuturau, Wyndham, Oteramika, Invercargill, Campbelltown, and Toetoes.

Lignite has been mined since the "seventies", but in the last decade its use as a fuel, both domestic and industrial, has increased, with a corresponding sharp rise in production. The greater quantity is won by stripping, but only at one pit is modern earth-moving and digging equipment used.

The development of the lignite mining industry is discussed, and estimates of the probable recoverable quantities of lignite based on old workings and outcrops, and of the inferred or hypothetical reserves in various areas are presented. The total lignite probably recoverable is 25,800,000 tons from the present workings, and the total inferred reserves 152,700,000 tons.

Areas recommended for drilling, should any large scale industry using the lignite be contemplated, are delineated.

An account is presented of the proposed methods of lignite utilization, together with laboratory comments on these proposals, particularly on the briquetting tests.

LOCATION

THE Mataura Valley lignite field referred to in this report is that area extending from Gore south to the coast, a distance of forty miles. The field in its northern part is bounded by the Hokonui Hills to the west, and the Clinton Hills to the east, but towards the coast it opens out in the Southland Plain, the river following closely the eastern margin of the plain, where it butts against the seaward hills. The towns of Gore, Mataura, Edendale, and Wyndham lie on the river, the first two being the most important. The area is well roaded and served by the Invercargill–Dunedin trunk railway.

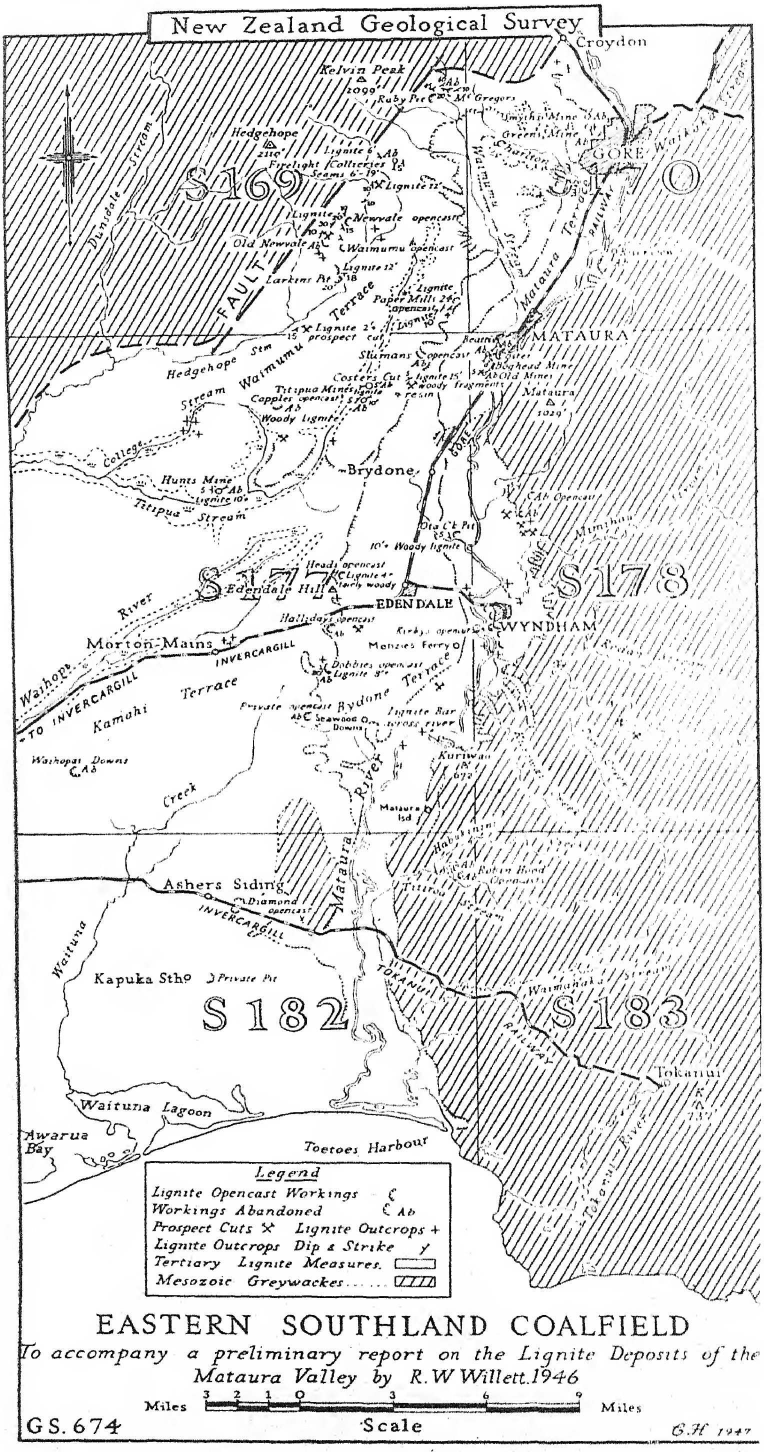


FIG. 1

Plan of Mataura Valley showing geology, topography, and lignite worki

North-west and north-east of Gore, on the Waimea Plains and the Waikaka-Pukerau area, the lignite deposits continue, but as they are not as extensive as they are in the main part of the field, the Mataura area, they are not considered in this preliminary report.

To the south and east the lignite measures occur under the gravels of the Southland Plains, and crop out here and there, where they are worked on a small scale.

The area discussed in this report lies within six Provisional One Mile sheets S/169, S/170, S/177, S/178, S/182, and S/183.

PURPOSE OF INVESTIGATION

The Southland lignites have for many years been a source of cheaply won low-grade fuel, and have served an ever-increasing household and industrial market. Recently, the briquetting and low temperature carbonization of the lignites has been proposed, and some investigation along these lines has already been carried out (1). The lignites occur over a wide area, and are worked on a small scale at many points, mostly opencast. Their wide and persistent distribution has suggested the presence of an extensive field, and various estimates have at times been made of the lignite available, but none based on geological grounds. Utilization of the Mataura lignites has now become a feature of local regional planning, and so field mapping was carried out in order to gain a clearer view of their extent and availability.

The object of this report is to present the results of the field work, with particular attention to the lignite deposits and to the areas suggested for future drilling investigation. The geology is not discussed in detail.

TOPOGRAPHIC CONDITIONS

The area occupied by the lignite measures lies between the Hokonui Hills in the west and Clinton Hills in the east. The Mataura River flows in an entrenched channel from Gore almost to Wyndham, but from Wyndham to the mouth at Fortrose the entrenchment is less pronounced and the river meanders to a greater degree. Over the Waimea Plains, north-west of Gore, the river is only slightly entrenched and has a fairly meandering course. There is a fall of six feet in the mile.

Bordering the river is a series of well marked terraces. The lowest, known as Mataura terrace, is 20 ft. above the river level and confines the present river. The next level is the 50 ft. Brydone Terrace, gravels of which are similar to those of the Mataura Terrace. The gravels of the present river are rounded cobbles and pebbles composed of greywacke, sub-schists, and quartz in even proportions.

Between the Brydone and the top terrace, the 100 ft. Waimumu, an intermediate level developed forming the greater part of the coastal plain, the 150 ft. Kamahi terrace, made up of well consolidated, but thoroughly leached, gravels. The quartz that makes up 60 per cent. of the gravels remains, the non-quartz rocks being all completely decomposed, giving a rusty-brown colour to the gravels. All the flat topped spurs that form the Waimumu district south as far as Pebbly Hills represent the Waimumu terrace level.

These terraces are important because where they cut across the lignite measures, and frequently at these places, opencast or sometimes

underground operations have been carried out. Most of the present strip workings are situated on the sides of the main Waimumu-Kamahi terrace level.

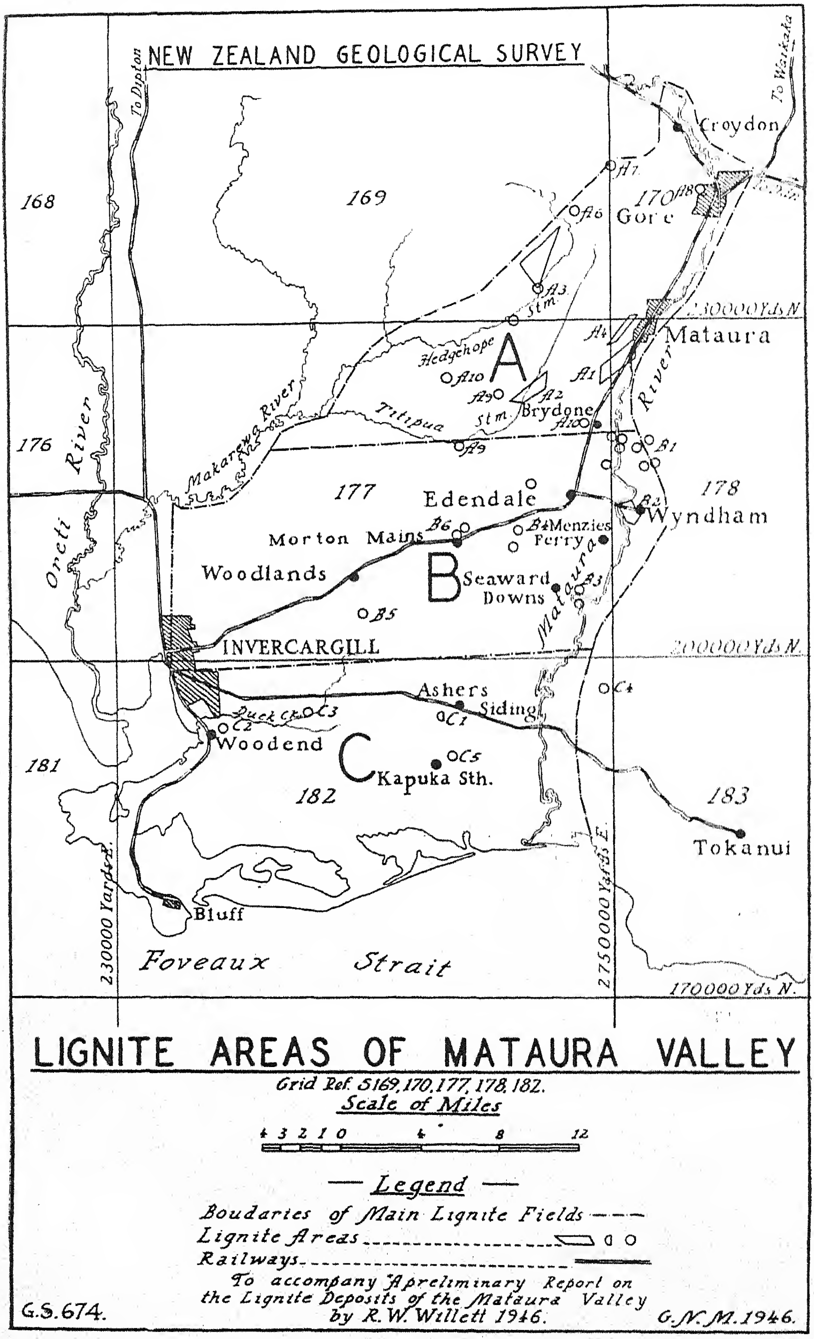


FIG. 2—Plan of Mataura Valley showing areas discussed quantitatively.

GEOLOGY

The following is the generalized stratigraphic sequence of the beds in the Mataura Valley :—

Age	Lithological Description	Local Name	Thickness
			(Feet)
Recent	River and terrace gravels, loosely consolidated, composed of greywacke and minor quartz cobbles and pebbles	Mataura Terrace	20
Pleistocene	River and terrace gravels, loose greywacke with minor quartz pebbles	Brydone Terrace	50
Pliocene Maori Bottom(?)	Rusty-coloured, decomposed greywacke-quartz gravels	Kamahi Terrace Waimumu Terrace	50–150
	Unconformity		
Middle Tertiary	Grey, greasy fine siltstones and mudstones with interbedded lignite and Carbonaceous shales. Auriferous		1,000
	Quartz conglomerate with fine, greasy, white mudstones		200
	Lignite seam with interbedded mudstones		1,000
Duntroonian	Fossiliferous sandstone, mudstones, calcareous sandstone		1,100
	Unconformity		
Jurassic and Triassic	Basement rock, indurated sandstones, claystones, and conglomerates		21,000

The above sequence of beds occurs on the west side of the valley, the lower beds being upturned at a fault contact with the basement rocks. On the east side of the valley the facies change and the fossiliferous beds are mudstones associated with lignite measures. The quartz conglomerates are absent. The fossiliferous beds occur at several points along the bank of the Mataura River between Mataura and Wyndham.

LIGNITE MEASURES

The lignite measures consist of a bedded greasy sandstone with interbedded lignite seams and carbonaceous shales. The mudstones at several places are bedded and carbonaceous. The seams range in thickness from 8 ft. to 65 ft., and at several places two seams are seen : in one case two are worked in the same pit—namely, at Larking's Hedgehope pit, where an upper seam of 10 ft. is separated from a lower seam, 15 ft. + thick, by 5 ft. of greasy mudstone. At the Mataura Paper Mills pit, the upper seam 20 ft. to 25 ft. is worked, and is separated by 5 ft. of greasy mudstone from an underlying seam of 10 ft. thickness. Splits such as these have been encountered in other workings such as at the Firelight workings, where the 6 ft. upper seam is separated by

5 ft. of greasy mudstone from a lower 19 ft. seam. It would not be correct to assume that these splits indicate two seams over the area, as the seams and the interbedded mudstones vary in thickness, the latter in places thinning out to produce some of the thick seams of lignite encountered, such as 64 ft. at the Waimumu workings. To what extent the seams are consistent and to what extent they thin and thicken is yet unknown, but it appears certain that they do vary, and this must be borne in mind when discussing the field.

There is some evidence to suggest that the lignite persists along the strike for a considerable distance, and then grades into carbonaceous shale. Nothing like that, however, has been encountered in any of the workings, but outcrops along the bank of the Mataura River suggest such a thinning. For this reason it has been considered reasonable to assume an extension of the lignite over an area 20 chains in radius from workings or good outcrops as a quantitative basis.

A change in lithology takes place from west to east. In the east the quartz conglomerates and fossiliferous sandstones are absent, being replaced by blue-grey siltstones, which are fossiliferous at several points of the Mataura River. Preliminary examination by Dr. Finlay and Dr. Marwick suggest that they are approximately equivalent in age (Duntroonian) to the fossiliferous sandstones of the west side of the valley (*i.e.*, Mandeville Road, Whisky Gully).

STRUCTURE

As to the south the area is completely blanketed by recent and older gravels, the Waimumu-Mataura area yields the most geological information.

The Tertiary beds have low dips, and over a large area strike north-east. They form a series of gentle folds with low dips (5°). The beds steepen as the western boundary is approached, where they are faulted against the Mesozoic basement rocks. The western fault boundary extends from Hedgehope River to the Croydon, then the boundary swings round a nose of basement rocks that lies between the Mandeville Road and the Waimea Plains, the fault itself continuing across the Mesozoic beds forming the nose. Near the west border an anticline, dipping 25° to 30°, trends parallel to the fault for a distance, then swings into it at the Mandeville Road.

To the south of Mataura near Brydone, a buried ridge of basement greywacke extends across the valley, the Tertiary beds having been stripped off it and replaced by recent gravels. The greywacke crops out in the face of the Brydone Terrace at Brydone, and this is the most westerly outcrop of the buried ridge. It marks an area where the lignites are absent.

On the east side of the valley the Tertiary beds form an erosion contact with the basement rocks, and here and there with remnants of the former Tertiary cover. The beds forming these remnants dip at low angles and do not suggest infaulting. At several points the lignite occurring in the outliers has been worked, but only on a small scale governed by the extent of the measures.

PRODUCTION AND GROWTH OF THE INDUSTRY

Records of the production of the larger operators are readily assembled, but the host of smaller operators and private pits whose exis-

tence was short or spasmodic make a complete compilation of the total production and history of the field difficult.

Over the whole area from the Waimea Plains to the lower Mataura Valley—in fact, eastern Southland—approximately one hundred and forty separate workings have at one time or other been operating. In 1945 there were sixteen lignite-pits producing in all 79,882 tons. Three, all in the Mataura area, produce over 10,000 tons annually—namely Boghead (11,019 tons), Hedgehope (11,128 tons), Mataura Paper Mills pit (21,375 tons).

Lignite production was well under way by 1886, when fifteen mines produced a total of 6,092 tons. Two mines, one at Wyndham and one at Gore, had been operating nine years prior to the first official record in 1886; thus the recorded production of lignite goes back at least to 1877. In 1881, McKay (2) recorded a thick bed of lignite being worked near the Mataura Bridge by Angus of Invercargill, and stated that it was being sent to Invercargill as fuel. Hutton (3) (1875) does not mention any working of lignite in the Mataura Valley, but in his report (4) of 1872 Hutton mentioned the presence of lignite there.

Official records commence at 1886, but before that time the quantity of lignite produced was probably not greater than 60,000 tons. Since that date the production of lignite in eastern Southland has totalled approximately 2,500,000 tons (1886-1944). This production is divided geographically as follows :—

	Tons
(a) Waimea-Waikaka, north of Gore area	394,938
(b) Gore-Waimumu-Mataura area	1,799,286
(c) Brydone-Edendale-Wyndham area	88,786
(d) Menzies Ferry-coast area	55,772
(e) Western part to the Aparima River	28,112
(f) Miscellaneous pits (not localized)	1,724
Total	2,368,618
Estimated before 1866	60,000
Grand Total	2,448,618

As will be seen, the greatest part of the total has been produced in the Gore-Waimumu-Mataura area, which is still the area that is responsible for 89 per cent. of the lignite production of eastern Southland. The largest producers lie within this area, one, the Boghead Mine, being the only underground workings in the whole area, and another, the Paper Mills Terrace strip mine, the largest producer.

In the past there have been several large underground workings—namely, Green's, at Gore (producing a total of 412,107 tons in fifty-two years), Beattie Coster's, in Mataura township (424,294 tons in sixty-seven years), the Mataura Colleries just south of the present Boghead Mine (249,790 tons in forty-eight years), Whiterig, near McNab (104,452 tons in fifty years), and the Boghead Mine at Mataura, still in operation (181,335 tons in the past forty years). The chief underground workings were all adjacent to rail at one of the larger centres in order to reduce haulage costs and so compete with the strip mines. Some of the smaller workings have in the past been opencast, and then for a short while, underground. In fact, all the underground operations began as strip mines.

The large scale operators generally work the one area for a considerable time, but smaller operators tend to move on once the over-

burden becomes too great for them to handle, or, in the case of those on the flats, water becomes a problem. This results in a large number of abandoned strip mines, and in places underground workings, over the whole area, that are now full of water or buried under slumped overburden. One reason for this is insufficient exploratory work in the initial stages ; drilling is carried out only by the larger operators who are in a position to afford it, while the smaller operators commence work on an outcrop, and, when conditions become too difficult, move to another spot.

The market has to a certain extent prevented any long range development, as it is only of recent years that the demand has been sufficient to permit the smaller operators to produce lignite on a paying basis. In the past most farmers had a small pit on their property from which they drew their domestic needs, but now practically all that has ceased and the local mines supply the farmers. A new feature over the past decade has been the increasing use of lignite as an industrial fuel. The New Zealand Paper Mills, for example, fire their boilers entirely on lignite from their own strip mine, about 100 tons per day, and the Waimumu Lime Co. burn lignite in their drier. With the difficulty of obtaining the sub-bituminous coals for domestic use, the lignites have now become firmly established in the domestic market, and the present number of operators (fifteen), can barely cope with the demand. It is even railed as far north as Dunedin. In eastern Southland the number of lignite workings has increased somewhat since the 1920's, but the rise in production has been much steeper.

The graph (Fig. 3) shows the total production of the eastern Southland lignite field, together with the total number of mines operating. It will be noted that increase in the number of such mines did not produce a corresponding rise in production. This is explained by the fact that the main variation in the number of mines operating was caused by increase in the number of private mines—*i.e.*, those operated spasmodically by a farmer for his own domestic needs. Over the last two decades the private mine has practically ceased to exist. A sharp continuous rise in production is indicated, commencing about 1935, and it will be noted that the number of mines operating is low and actually shows a decrease. This production rise results from an increased demand for the lignite fuel for both domestic and industrial purposes, and increased use of mechanical earth moving and digging gear.

DEVELOPMENT

There has been no systematic development of the area. Outcrop mining has been the general order of things, and even to-day in only one opencast pit, the Mataura Paper Mills, do the operators use modern mechanical earth-moving machinery, with a consequent greater efficiency of production. The initial stripping in some cases is to-day carried out by a bulldozer, but the digging and loading of the lignite is still largely by manual labour.

The plan (Fig. 1) shows the location of all the present workings and most of the past workings. It will be seen by comparing these plans and the topographical maps that the operations are confined to the flats or creek valleys and to the terrace faces. The terraces have offered, and still offer, the most interest to opencasters because of good drainage ; and where the lignite outcrops indicate a reasonable quantity, much of it can be won before the overburden to lignite exceeds 1 to 1. The lignites crop out along the terrace faces where not completely

obscured by gravels, with the result that many workings in the past have followed these outcrops. The same applies to a less extent to the outcrops on the flats and creek beds, but the flats have generally been the scene of underground workings.

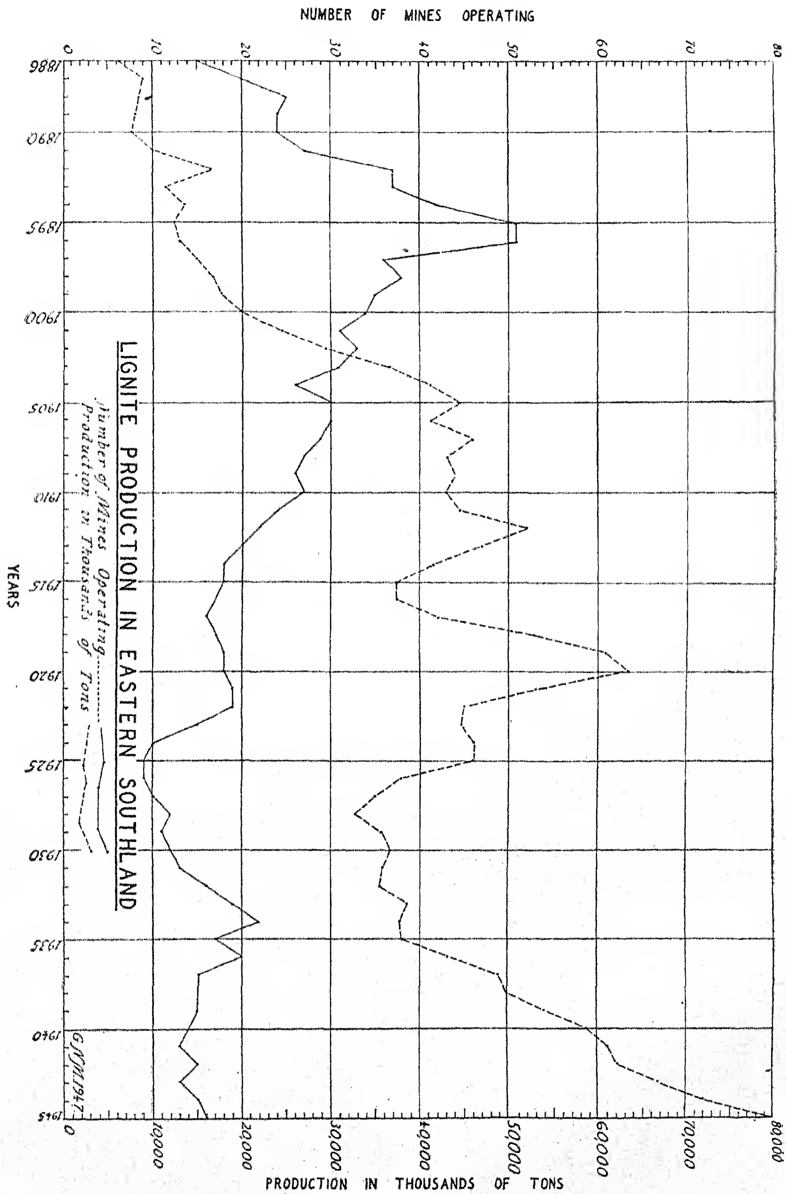


FIG. 3—Graph showing annual lignite production and number of mines operating.

Green's, Beattie Coster's, and Mataura Collieries and the present Boghead, all underground mines, are located in the Terrace flats, Green being on the flat formed by the Waimumu Terrace, the others all in the Mataura Terrace. Most were started at the beginning by opencast workings at the outcrops, but water and stripping soon forced the operator to work bord and pillar underground.

The lowest terrace level, the Mataura, has been the scene of a considerable amount of mining, particularly in the vicinity of the town of Mataura ; up to 1945 approximately 850,000 tons have been taken from this terrace. At present only two mines are operating in it. Only at a few places has the face of this terrace been worked, but over its surface lignite has been found and exploited at depths ranging from a few feet to 30 ft.

The greater part of the lignite won in the Ota Creek - Wyndham area has come from workings on Mataura Terrace ; and water in most cases has been the chief problem as the water table and top of the lignite are very close.

The next terrace, the Brydone, has not had such development ; in fact, only where the Brydone Terrace merges with the Kamahi or Waimumu and cuts across the measures has any lignite been worked. At the base of the Kamahi Terrace on Brydone Terrace flat there has in the past been some scattered small workings, particularly in the Edendale area.

On the east side of the river at Riverview, four and a half miles up-stream from Mataura, strip and underground work was carried on at various intervals from 1891 to 1932 on a relatively small scale in the face of Brydone Terrace.

At the Kamahi Terrace there has been little development, but there is evidence of extensive lignite deposits over this level, from the Edendale Hill to the coast at Invercargill. The lignite is frequently encountered in well-sinking, drainage, and other excavating operations over this area. It has been worked at Woodlands and Woodend, and is still worked at Asher's Siding, where 53,372 tons have been won in the past forty-three years. The lignite of the southern part of the Kamahi Terrace level is of a slightly lower grade, that at Asher's Siding as low as 6,930 B.T.U's. per pound. At the northern part of the Kamahi Terrace, where several streams have formed long, shallow gullies in the Waimumu Terrace down to the Kamahi level, the valley has been worked at several places, notably in the Titipua Valley. It is along these valley floors that suitable areas for opencast work could be proved. Water has been a problem with the small scale operator, for the lignite is just below the creek level, and the valley floors, being flat and swampy, flooding is an ever-present danger.

On the west side of the wide valley of the upper Hedgehope Stream, cut in the Waimumu Terrace down to the Kamahi Terrace level, two seams of lignite are worked opencast at Larking's, where 52,147 tons have been won since 1939.

The Waimumu Terrace has been the scene of considerable development ; in fact, as much quantitatively as the Mataura Terrace, but distributed over more producers. Green's mine was on this terrace just west of Gore, and produced 412,107 tons in twenty years. The largest opencast in the district located on the face of this terrace, the Mataura Paper Mills pit (150,176 tons to 1945), is just above the Brydone Terrace level west of Mataura.

At the Waimumu Terrace level and on ridges above it there has

been, and is at present, considerable mining along the western margin of the field, where the lignite measures steepen up against a fault contact with the Hokonui basement rocks. In the area Brydone–Waimumu, the Raby, Newvale, New Hakatere, and Waimumu strip mines are worked, and in the past double this number have been worked in this area. The overburden-lignite ratio varies considerably over the western part of the field as the dip of the measures increases to its maximum of 40°. Because of this, there have at times been several underground workings in this area, but the distance from the centre of demand prevented successful competition with the strip mine, and to-day all operations in the Waimumu Terraces are strip mines.

PROBABLY RECOVERABLE AND INFERRED RESERVES

It is not possible, nor is it the purpose of this report, to present estimates of proved recoverable lignite. This must wait until drilling has been carried out over selected areas. The field data obtainable in Mataura Valley are scanty, the reason being that recent and late Tertiary gravels blanket the underlying lignite measures. The estimates given are in two groups, one group regarded as probably recoverable and the other inferred reserves. That constituting the probably recoverable group is considered as an area of 20-chains radius around present or past workings. Calculation of quantities were made on the basis of 1,000 tons per acre-foot.

PROBABLY RECOVERABLE

Under this heading only areas that are adjacent to or extensions of past or present workings are considered and small outcrops are neglected. Assumption is made that where the lignite dip is low or flat the overburden-lignite ratio does not become greater than 3 to 1. In the case of underground workings 55 per cent. is considered as the amount probably recoverable.

INFERRED RESERVES

Areas where there is an outcrop of lignite or evidence of some past workings that have now been practically obscured by slumping and collapse are placed in this group. Inferred reserves must be regarded as fairly hypothetical, but do suggest areas where drilling would be advantageous in the search for a large area of recoverable lignite.

For quantitative purposes the Mataura Valley is discussed under the areas described before in order of productive importance, the Waimea-Waikaka area being omitted from the preliminary report.

A. *Gore-Waimumu-Mataura-Brydone Area*

The Gore-Waimumu-Mataura-Brydone area is bounded by the Mataura River in the north, the Hokonui Hills to the west, and their eastward extension to the east, and the southern boundary is an arbitrary east-west line near Brydone on the 220 north grid line of the Provisional One Mile sheets. The production from this area up to the end of 1945 was 1,810,641 tons, which represents 76 per cent. of the total lignite production of Eastern Southland.

A. 1—The Mataura Terrace level, present in the area from Mataura south to the Brydone Terrace, is perhaps the most promising area in the whole field. That part of the area immediately adjacent to Mataura has been worked in the past, and is at present being worked by one underground mine. To the south of the worked areas the New Zealand Paper Mills Co. drilled an area, but the results of this work are not available. The lignite measures dip at low angles (5°) to the north-east. The producing lignite seams in the vicinity of Mataura appear to be fairly consistent over the area, and average 18 ft. thick. Allowing the extension of the seam over a semicircle of 20 chains radius adjacent to past and present workings, the probably recoverable lignite, less the amount already won, represents 2,500,000 tons. This is considered to be probably recoverable from underground workings as the overburden-lignite ratio is 1 to 1 over a small area only and rises to the north-west. The inferred reserves are considered to occupy a parallelogram of 1,600 acres extending from the river at Mataura along the strike of the measures to the base of the Brydone Terrace. The inferred reserves represent 27,000,000 tons. The greater part of these reserves would, if proved, be recoverable if strip-mining methods were permitted by the overburden ratio; but underground methods would greatly reduce the recovery percentage. Any suggestion of the extension of the lignite beyond the area of inferred reserves in the north is little short of guesswork, although over the flat as far as Gore lignite is known to occur at widely spaced points. Near Brydone the basement *Hokonui rock crops out*, forming a gorge in the river and a bluff on the Brydone Terrace. This basement separates the Mataura area from the Edendale area, and means that the measures are missing over the area north of Brydone.

A. 2—The Kamahi Terrace level, where it joins the Waimumu, and the stream flats at that level offer at several places potential areas of lignite reserves, the Titipua and Hedgehope particularly. On the flats of these streams there have been several opencast workings, and fairly large opencasts are being operated to-day in the Hedgehope—*e.g.*, Larking's Hedgehope Pit.

The probably recoverable quantity at the Kamahi Terrace level in the flat of the Titipua, with an average thickness of 10 ft., is 2,500,000 tons, and the inferred reserves is 19,200,000 tons.

A. 3—The Hedgehope flat is worked at Larking's, and beyond these exposures there is nothing to indicate the extent of the lignite. Two seams, 10 ft. and 13 ft., are worked, and the probably recoverable tonnage in this area 2,500,000 tons. No estimate is prepared of inferred reserves.

A. 4—On the eastern slopes of the Waimumu terrace, where the Brydone and Kamahi merge with it in the vicinity of the Paper Mills Pit, and south to Coster's Edendale pit, is a strip where a fair quantity of opencast lignite may occur. The proved recoverable lignite of an average thickness of 20 ft. is 6,300,000 tons, and the inferred reserves are placed at 19,200,000 tons. The general overburden-lignite ratio is 1 to 1, but west of the terrace face it increases.

A. 5—To the west on the Waimumu Terrace level the area adjacent to the Waimumu and Newvale workings offers possibilities as a large reserve of lignite. The average thickness is 25 ft.; on this basis the probably recoverable is placed at 6,000,000 tons, and the inferred reserves at 42,000,000 tons.

A. 6—The Firelight area was worked for a short while, and a thickness of 12 ft. is indicated. The angle of dip is low, and the lignite was

worked in opencast and bord and pillar. The probably recoverable is 1,500,000 tons, and the inferred reserves are placed at 3,000,000 tons.

A. 7—In the vicinity of the Raby pit the lignite is 30 ft. thick, and dips east at 35°, and here it is estimated that the probably recoverable is 960,000 tons, and the inferred reserves 4,400,000 tons.

A. 8—Green's Mine, in the Waimumu level west of the river, worked 20 ft. of lignite over an area of 30 acres, and won 412,107 tons by bord-and-pillar methods. The probably recoverable, less the area worked, is placed as 1,000,000 tons and the inferred reserves as 4,400,000 tons.

A. 9 and A. 10—Two other small workings and the reported presence of lignite in water wells scattered over the area are considered to represent inferred reserves of 3,700,000 tons.

The following table shows the quantity of the Gore-Mataura area :—

Locality	Average Thickness (Feet)	Probably Recoverable (Tons)	Inferred Reserves (Tons)
A. 1	18	2,500,000	27,000,000
A. 2	10	2,500,000	19,200,000
A. 3	10/15	2,500,000	n.d.
A. 4	20	6,300,000	19,200,000
A. 5	25	6,000,000	42,000,000
A. 6	12	1,500,000	3,000,000
A. 7	30	960,000	5,600,000
A. 8	20	1,000,000	4,400,000
A. 9	10	n.d.	2,500,000
A. 10	5	n.d.	1,200,000
Total ...	...	23,260,000	124,100,000

B. *Brydone-Wyndham-Edendale-Mataura Island*

This area extends south from area A to the 200 north grid-line near Mataura Island. It is bounded on the west by Titipua Creek, and on the east by Mataura River.

Development has not been extensive in this area as the Gore-Mataura area, nor are the indications of the extent and thickness of the lignite seams as plentiful. The greater part of the area is blanketed with 10 ft. to 50 ft. of recent and later Tertiary gravels.

B. 1—The Ota Creek pit on the Mataura Terrace is the only one operating at the present time, although there have been in the past numerous small-scale operations over the area, particularly in the vicinity of Wyndham township. The thickness at Ota Creek is 10 ft., and the amount probably recoverable is placed at 1,300,000 tons. The inferred reserve of 6,300,000 tons is based on the presence of numerous small workings, and well hole information in the area.

B. 2—The area adjacent to Wyndham on the west bank of the Mataura is considered, on the evidence of old pits and numerous water-wells, to have an inferred reserve of 8,800,000 tons.

B. 3—In the Mataura River lignite outcrops at Seaward Downs, and was encountered during pile-driving operations at the Bridge. Here the inferred reserves over the area are placed at 1,200,000 tons.

B. 4—Along the face of the Kamahi terrace lignite has been worked opencast in the past at several places. These workings are now almost completely obscured, and the true thickness is unknown. The average

of the thicknesses mentioned in the official records is 8 ft. The inferred reserves along the east face of the Kamahi Terrace are placed at 4,000,000 tons.

B. 5—On the Kamahi Terrace level a 14 ft. lignite seam was once worked at Waihopai Downs, and it has been encountered at various points during well-sinking and ditching. The inferred reserves are placed at 3,500,000 tons.

B. 6—Lignite was uncovered during drainage operations near Morton Mains settlement. The full thickness is not known, but, allowing an arbitrary thickness of 5 ft., the inferred reserves over a 20-chain radius are 600,000 tons.

The above estimates of the Brydone-Mataura Island area are summarized in the following table :—

Locality	Average Thickness (Feet)	Probably Recoverable (Tons)	Inferred Reserves (Tons)
B. 1	10	1,300,000	6,300,000
B. 2	10	n.d.	8,800,000
B. 3	?5	n.d.	1,200,000
B. 4	8	n.d.	4,000,000
B. 5	14	n.d.	3,500,000
B. 6	5	n.d.	600,000
Total ...	...	1,300,000	24,400,000

C. Mataura Island, Seaward Downs, to the Coast

This area extends from area B to the coast, and from Mataura River in the east to Waihopai River in the west.

Lignite has been worked at Woodend, and for the past forty-three years at Asher's Siding, where 53,372 tons have been won to date. This entire area lies on the Kamahi Terrace and extends to the coast.

C. 1—The lignite at Asher's is a slightly lower grade than the Mataura, having a lower calorific value and a higher moisture content ; a thickness of 36 ft. is worked. The probably recoverable quantity in the area is placed at 2,200,000 tons. The lignite is practically horizontal, and is covered with weathered greywacke-quartz Kamahi gravels, and the ratio of stripping to lignite is at present 1 to 3. It is probable that there is an extensive area of lignite here, but there is insufficient evidence without drilling to indicate the full extent of the deposit ; however, the reserves should at least be as great as anything in the Mataura area. If the thickness is constant, the inferred reserves will be of the order of 36,000 tons to the acre.

C. 2—The lignite was once worked at Woodend, and, on this evidence the inferred reserves are placed at 880,000 tons.

C. 3—An outcrop of lignite at Duck Creek is given the arbitrary thickness of 5 ft., and inferred reserves of 600,000 tons.

C. 4—On the eastern bank of the Mataura at Robin Hood, in a small patch of lignite measures, 12 ft. of lignite was once worked. The area was worked in a small way, producing 3,787 tons in thirty-four years. The inferred reserves are placed at 1,500,000 tons, and as marks of old workings are obscured it is unwise to estimate the probably recoverable quantity.

C. 5—A small private strip mine near Kapuka South worked 10 ft. of lignite for many years, under a few feet of stripping. The total thickness is not known. Inferred reserves over an area of 20 chains radius are 1,250,000 tons.

The results are summarized in the following table :—

Locality	Average Thickness (Feet)	Probably Recoverable (Tons)	Inferred Reserves (Tons)
C. 1	36	2,200,000	36,000 tons to the acre
C. 2	7	n.d.	880,000
C. 3	5	n.d.	600,000
C. 4	12	n.d.	1,500,000
C. 5	10	n.d.	1,250,000
Total ...	...	2,200,000	4,230,000

Summary

The total reserves of the Mataura Valley from Gore to the coast are as follows :—

Probably recoverable ... ... 25,760,000 tons.
Inferred reserves ... ... 152,730,000 tons.

Recommendations for Future Drilling

Any future drilling in order to prove recoverable tonnages over any part of the Mataura Valley will be confined to certain areas by consideration of transport and distance from centre of use.

The areas discussed under the section on probable reserves indicate automatically the areas where drilling is likely to indicate a considerable lignite tonnage. Those areas where a large inferred reserve is shown are given first place for future exploratory work.

A. *Gore-Waimumu-Mataura-Brydone Section*

The most attractive section of this area is the Mataura Terrace level adjacent to Mataura, and the east face of the Waimumu Terrace. Both are close to centres and rail. Drilling is recommended along the strike of the measures in area A. 1 and in area A. 4.

To the west the Titipua area, A. 2, about seven miles from Mataura by road, offering an area of inferred reserves of 19,200,000 tons, definitely needs exploration. The land over the area is not such high class farm land as that of A. 1, which, in view of the possibility of large opencast workings, is an important factor.

Area A. 5 has a large potential reserve that offers good opencast possibilities, but it is eleven miles by road from Mataura or Gore. Coupled with this area is A. 3, the Hedgehope Stream Valley, where two seams are worked opencast about one and a half miles south of A. 5. This is insufficient information at present to infer reserves, but the area offers good conditions for strip mining operations.

Other areas discussed in the previous section do not offer such a large inferred reserve, and for that reason it is unlikely that they would be drilled in preference to the areas named above.

B. *Brydone-Edendale-Wyndham-Mataura Island Section*

The Ota Creek area, B. 1, on the Mataura Terrace flat, offers a fair reserve tonnage under suitable strip-mining conditions. Should any

large tonnage of lignite be required south of the Gore-Mataura section, this is the most attractive area.

The Wyndham area, B. 2, has all the indications of a large area of horizontal lignite, but the presence of the township over the area must restrict any operations. Strip-mining operations would have to contend with considerable water. Both B. 1 and B. 2 are fairly handy to the Wyndham-Edendale branch railway.

Of the other areas in the section, B. 5, although the inferred reserves are based on scanty information, offers suitable drilling areas adjacent to the main railway line, and a thin cover at ten to fifteen miles from Invercargill. It is probable that the lignite over these areas will be lower in grade than that in the Mataura area, and comparable to the Asher's Siding material.

C. *Mataura Island-Woodend-Coast Section*

The only area of interest from the point of view of future development is the Asher's Siding. The lignite is lower in grade than that of Mataura, but strip-mining conditions are good, and the land is not first-class farming land. The deposit is adjacent to the Invercargill Tokonui railway, being eighteen miles from Invercargill. The inferred reserves are of the order of 36,000 tons to the acre. This is the largest area of potential reserves close to Invercargill, and the largest where strip mining would not destroy first class farming land.

Of the other areas discussed in this section, C. 4, at Woodend, offers another possible area of investigation. This area is close to the Bluff line, within seven miles of Invercargill. Again it is not an area of first-class land and offers good strip-mining possibilities for a grade of lignite probably the same as that at Asher's Siding.

ANALYSES

The following table shows the proximate analyses of samples taken from present and abandoned pits in the Mataura Valley. Ultimate analyses have also been carried out, but are not included in this preliminary report.

The analyses indicate that the quality is fairly consistent over the area, but the samples from the south part of the area are slightly lower in grade, have lower calorific value and higher moisture content for the air-dried coal.

UTILIZATION

Local committees and the Southland Regional Planning Council are pressing for briquetting, carbonization, and gasification experiments using the Mataura lignites, in order that the lignites may form the basis of a large industry developing a processed product rather than merely the sale of raw lignite.

Locality, etc.	Loss on Air Drying	M.	V.M.	F.C.	A.	S.	B.Th.U./lb. Calorific Value	Extraction with Benzol		C.S. No.
								Extract (per cent.)	Range	
Boghead (Rowe's)—(underground)	14.5	29.8	37.9	27.3	5.0	0.5	7,290			264
,,	15.5	29.3	37.1	29.4	4.2	0.5	7,300			265
,,	14.8	30.5	36.0	29.1	4.4	0.4	7,080			266
,,	13.0	29.3	36.8	27.8	6.1	0.5	7,210	2.1	62-68°	682
,,	—	29.7	36.1	29.2	5.0	0.4	7,300			683
(opencast face)	12.4	23.9	37.7	28.4	5.0	0.5	7,550	2.9	63-68°	681
	14.0	28.7	36.9	28.5	4.9	0.5	7,288			Mean
Duncan's Road (opencast face)	10.6	24.9	39.4	30.7	5.0	0.8	7,980	3.8	63-68°	674
Firelight Colleries—(underground)	10.5	23.5	40.4	32.9	3.2	0.8	8,010	2.1	63-68°	675
Mataura (Beattie Coster's)—	15.2	29.3	37.1	27.7	5.9	0.5	7,340			261
,,	13.9	31.4	35.7	28.4	4.5	0.5	7,020			262
,,	18.2	33.4	34.7	27.7	4.2	0.5	6,820			263
	15.7	32.7	35.8	27.6	4.9	0.5	7,060			Mean
McGregor's Raby—(opencast)	11.6	25.2	39.9	30.4	4.5	0.3	7,860	3.4	63-70°	669
New Hakatere opencast)	12.1	28.1	37.4	30.2	4.3	0.3	7,410	4.5	63-69°	673
Newvale—(opencast)	14.7	26.8	38.2	31.3	3.7	0.4	7,660	2.0	63-67°	671
Hedgehope Larking's—(opencast) Upper seam	12.8	27.7	37.4	30.7	4.2	0.6	7,720	3.8	61-66°	676
Lower seam	13.4	26.7	40.3	28.6	4.4	0.6	7,760	3.1	63-69°	677
Paper Mills' Terrace—(opencast) Upper seam	14.6	30.4	39.2	26.3	4.1	0.2	7,330	3.3	61-67°	678
,,	nil	21.8	43.1	29.5	5.6	0.2	8,010	4.1	62-67°	679
,,	nil	21.4	43.1	30.0	5.5	0.5	7,980	n.d.	n.d.	942
	—	24.5	41.8	28.6	5.1	0.3	7,770			Mean
Lower seam	14.3	34.4	39.9	17.2	8.5	0.3	6,280	3.3	63-68°	680
Raby, old pit (opencast)	—	17.0	54.2	30.4	4.8	0.4	8,330	3.8	62-70°	670
Waimumu Workings—(opencast)	13.7	26.5	40.5	29.6	3.4	0.5	8,250	4.0	63-69°	672
,,	8.7	27.0	40.6	29.6	2.8	0.6	7,960	—	—	L. 34-1
,,	22.0	23.1	42.2	32.1	2.6	0.4	8,510	—	—	34-2
,,	11.3	26.0	40.8	30.4	2.8	0.4	8,100	—	—	34-3
,,	7.0	31.2	39.5	26.4	2.9	0.3	7,450	—	—	34-4
	12.5	26.7	40.7	29.6	2.9	0.4	8,054			Mean
Coster's Edendale pit	5.6	26.3	40.1	27.2	6.4	0.3	7,460	3.9	61-67°	668
Ota Creek—	18.9	30.3	40.7	24.9	4.1	0.3	7,300	5.0	63-68°	667
Asher's Siding	12.0	32.7	37.8	25.1	4.4	0.6	6,930	3.4	64-69°	666
Gladfield—	11.6	35.7	24.4	34.2	5.7	0.3	6,400	2.6	62-68°	665

BRIQUETTING

Experimental briquetting trials carried out at the plant of the Victorian State Electricity Commission were reported on by W. G. Hughson, of the Dominion Laboratory (C.S.R. 164, 4/6/46). The results are summed up in his conclusion:—

> Coal from the Mataura Paper Mills pit containing 21.4 per cent. moisture on the air-dried coal does not make a satisfactory commercial briquette by the use of pressure alone.
>
> Variations in the amount of fine material in the mixture, reductions in the moisture content, and increase of pressure up to 15 tons per square inch failed to produce any improvement in the strength of the product.

Since then further experiments carried out in the Dominion Laboratory at Wellington indicate that the amount of moisture in an air-dried coal is the critical factor in determining whether the briquette will be satisfactory or not.

The Coal Survey Committee, in a memorandum to the Mataura Lignite Committee, 27th September, 1946 (5), states:—

> The binderless briquetting of Southland lignite seemed to offer some promise of a useful means of utilizing this fuel. In view of the negative results obtained in the test at Yallourn, further comparative tests on samples briquetted in New Zealand and the sample used in Australia have been carried out.
>
> The coal experimented with in Australia came from the Mataura Paper Mills pit, from the upper seam, and from an old dried-out working-face. The analysis of the "air-dried" coal gave a moisture content of 21.8 per cent. Other Mataura samples whose analyses were given in a report (5) show a much higher moisture content on the "air-dried" coal—*e.g.*, 30.4 per cent. for C.S. 678. Comparative briquetting tests between two coals from the Mataura Paper Mills pit, which air-dried respectively to 21.8 and 30.4 per cent. moisture, lead to the following conclusions:—
>
> (1) Coal A (21.8 per cent. moisture on air-dried basis) gave briquettes that were much weaker than briquettes made from Coal B (30.4 per cent. moisture on air-dried basis). (Both coals were dried to 10 per cent. moisture prior to briquetting.)
>
> (2) Coal A briquettes, even when made with pressures up to 25 tons per square inch, were easily broken by hand.
>
> (3) Coal B briquettes made with 15 tons per square inch pressure could not be broken by hand.
>
> It is therefore apparent that lignite that retains 30 per cent. moisture on air drying gives a much harder briquette than a similar coal that dries to 20 per cent. moisture. From one pit it is possible to obtain coal that briquettes very well, and also coal that gives an unsatisfactory briquette. This fact requires further investigation to determine the significance of the moisture content of the "air-dried" coal. It also means that for briquetting purposes the reserves of lignite must be classified more strictly and allowance made for their capacity to retain moisture or for the related factor that results in a stronger briquette. Experiments using a bitumen binder have also been conducted and show that the usual amount of binder (say, 8 per cent.) is required to make a satisfactory briquette.

The sample forwarded to Victoria was taken from a disused and thoroughly-dried-out face. A sample from a similarly dried face in the Raby Pit (C.S. 670) showed an even lower moisture content, 17.0 per cent. Samples from Duncan's Road Pit and Firelight Collieries, both abandoned, when air-dried contained 24.9 and 23.5 per cent. moisture respectively. All samples taken from fresh working-faces showed moisture content when air dried ranging from 35.7 per cent. to 23.1 per cent., the average being 27.7 per cent. Further trials will be carried out in samples from the Mataura area, Ota Creek area, and Asher's Siding near Invercargill.

CARBONIZATION

Although experiments have been made on the carbonization of Yallourn lignite, carbonization has not been carried out commercially, nor is it likely that such treatment would be applied since the products from this type of coal would be of doubtful value (memo. 29/9/46).

GASIFICATION

The same memo makes the following comment on gasification of lignite :—

Gasification of lignite which has been investigated in Australia and operated in Germany and elsewhere does not involve carbonization as applied to higher-grade fuels. With lignite the gasification process involves the conversion of practically all the fuel into gas in specially-designed producers. Some systems, such as that used in Australia, require the lignite to be briquetted prior to gasification, but at least one German process uses the fuel in a finely divided state. The gas obtained from these processes is of low heating value and would require enrichment before it could be used as town gas. Three ways of enrichment may be considered :—

(1) Enrichment by adding petroleum-oil or coal-oil to the producers during gasification, as in the production of ordinary carburetted water-gas.
(2) By adding undiluted coal gas from normal gas-retorts using good-quality gas coal.
(3) By synthesizing methane from a portion of the gas and adding the methane to the remainder. This latter process has been considered in Australia but is still in the experimental stage.

Work on the catalytic conversion, to methane, of hydrogen and carbon monoxide has also been engaging the attention of the Gas Research Board in Great Britain.

The following recommendations are presented by the Coal Survey Committee on the utilization of lignites :—

(1) The nature and quantity of the reserves of coal available over the whole field should be determined in greater detail and with due regard to variations on analysis.
(2) Further briquetting trials should be proceeded with as this would seem to offer the best prospects for a major industry.
(3) Carbonization experiments are not favoured except in conjunction with any briquetting scheme. The main product of carbonization is the solid residue; the gas and oils having by-product value only.
(4) Complete gasification is not yet a commercial proposition except under special circumstances.
(5) In certain cases the raw coal could be burned in special equipment, but for this purpose it could not be transported for any great distance.
(6) Owing to the scope in Southland for the development of hydro-electric schemes the development of electric power from coal may not prove desirable.

REFERENCES

(1) HUGHSON, W. G. (1946): Briquetting of Mataura Coal in Australia. *Coal Survey Report, C.S.R. 164.*

(2) McKAY, A. (1881): Mataura Plant Beds, Southland County. *Rpt. Geol. Expl. for 1879-80*, No. 13, 39-48.

(3) HUTTON, F. W. (1875): "Geology of Otago." Mills Dick and Co., Dunedin.

(4) HUTTON, F. W. (1872): Reports on the Geology of Southland. *Rpt. Geol. Expl. for 1871-72*, No. 7, 89-112.

(5) *Coal Survey Letter, C.S.L. 289*, 29-9-45.

KAWAU COPPER MINE—SELF-POTENTIAL ELECTRICAL PROSPECTING

By H. W. WELLMAN, Geological Survey, Department of Scientific and Industrial Research.

(Received for publication, 19th August, 1947)

Summary

Self potential electrical prospecting for copper lodes at Kawau Island is described and the results illustrated by maps and diagrams. The known lode is well defined by potential variations but does not appear to extend beyond the limits of the old workings.

INTRODUCTION

Kawau Island is a small island in the Hauraki Gulf 30 miles due north of the city of Auckland. The old mine is at the foot of steep cliffs on the south side of the island (Fig. 1). The mine was worked in the middle of the last century and is the only copper mine which has been worked with profit in New Zealand. The exact reason for the closing of the mine is not known but it is probable that the mine became less productive at depth. Cox (1882) examined it after it had been closed down and had no doubt that the mine would pay if reopened and worked in conjunction with the manufacture of sulphuric acid. Ferrar (1934) summarized the previous literature dealing with the mine and geologically mapped both Kawau Island and the adjoining mainland.

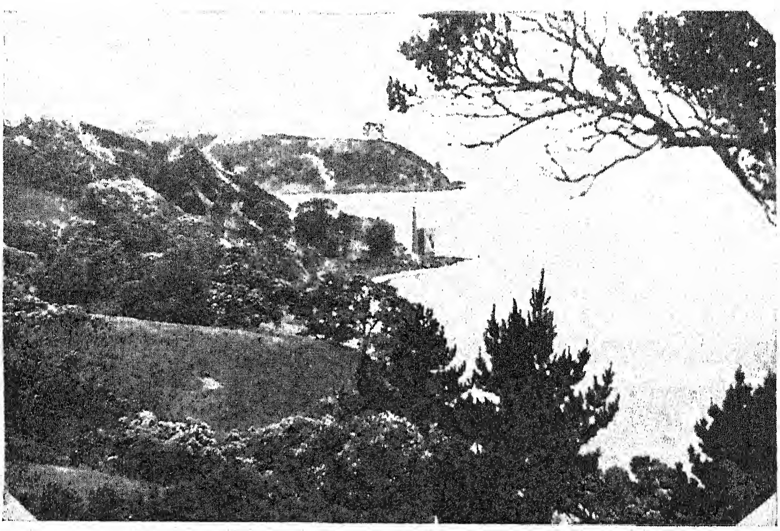


FIG. 1.—Site of old copper mine Kawau Island, the chimney is at Copper Mine Point.

The latest account is by Henderson (1939) who states:—"Mining began at Kawau in 1842 and more extensively in 1846, and in a few years £60,000 worth of ore was produced. Later the shaft, which is on the beach below high-tide level, was deepened to over 200 feet. Records

of this early work are fragmentary. An attempt was made to reopen the mine in 1900, but there was practically no production. The crushed and silicified jasperoid slates in which the copper-ore occurs strike across the island, their outcrop being marked by ironstone gossan and masses of oxide of manganese. In depth the ore consists of nodules and lenses of pyrite and chalcopyrite. At the mine the ore is said to have ranged from 6 feet to 15 feet in width and to have contained on the average 16 per cent. of copper (Hector (1869); Ferrar).

The electrical survey described in this report was an attempt to trace the copper lodes beyond the area of old workings and to find any other areas that might be worth drilling. The work was done in December, 1941, and took two weeks. The author was assisted in the field by Mr. H. J. Harrington.

GEOLOGY

There are two main groups of rocks at Kawau Island—the undermass of greywacke, and argillite with minor bands of jaspillite and the unconformably overlying Tertiary strata composed of conglomerate, sandstone, calcareous grit, and mudstone. In general the greywacke and argillite are so deeply weathered that the bedding planes cannot be recognized. The jaspillites are jointed but little weathered, and many of the bedding planes are visible. At Copper Mine Point the bedding planes are parallel to the lodes. The copper lodes lie within a band of jaspillite that forms a prominent point on the coast (Copper Mine Point) and extends inland for several chains as a well-defined ridge.

The basement rocks are closely and irregularly folded and faulted and in general strike north but considerable variations in this strike are frequent. The dip of the beds is usually at high angles. The Tertiary beds were deposited after the deformation of the basement rocks and probably after the formation of the copper lodes. These Tertiary beds, together with the basement, were later somewhat deformed and the elevated part of the Tertiary beds and undermass removed by erosion. An extensive senile erosion surface, now from 400 to 500 feet above sea-level at Kawau Island, truncates both the basement and the Tertiary beds, and indicates a long period of stillstand when the land was lower than at present. Still later the land was elevated and valleys cut in the erosion surface, the land was then lowered to its present position so that the lower parts of the valleys were drowned to form shallow estuaries such as Auckland Harbour; at the same time isolated hills such as Kawau were separated from the mainland to form islands.

These comparatively recent changes in the position of sea-level must have changed the groundwater level at the copper lodes and have to be considered with respect to the level of possible secondary enrichment.

OLD WORKINGS

Many of the old workings above sea level are still open but the timber has rotted and the roofs of the drives have collapsed in many places. The position of the old workings and the copper lodes are shown by Fig 2. The drive along the east lode can still be followed with some difficulty for 300 feet. It enters the hill 100 feet north-east of the engine-house chimney and follows the lode which strikes 25° east of north. At 150 feet from the entrance this drive connects with the bottom of a shaft, still open and 100 feet deep. Ore has been stopped out from

several places along this drive but the workings do not appear to have reached the surface. At two places there are connections with lower workings below sea-level and full of water which could not be examined.

From the west side of Copper Mine Point a cross-cut extends through the point to the entrance of the drive along the east lode. The west end of this cross-cut crosses the line of the west lode. This lode was worked seaward but apparently peters out to the north for no traces of copper and very little gossan were seen in the cross-cut.

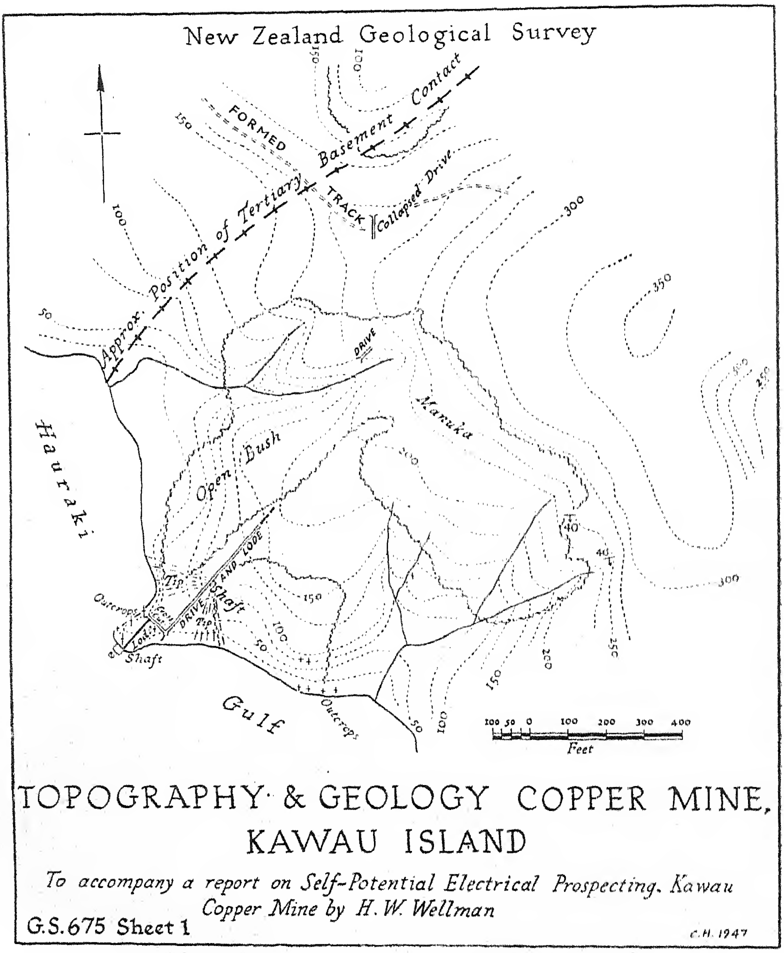


FIG. 2—(Caption on Map, G.S.675, Sheet 1).

Hector (1869, p. 45, Fig. 1) shows the east lode as the faulted continuation of the western, but no fault capable of causing this displacement was seen in the well-exposed surface exposures between the cross-cut and the engine-house. Unless there is better evidence for this fault in the lower workings it seems more likely that the two lodes are distinct and arranged in echelon.

If copper lodes at Kawau Island are confined to bands of jaspillite then the chances of future discoveries are much lessened, for bands of jaspillite usually form ridges and these, especially between Copper Mine Point and Bon Accord Harbour, have been well prospected.

PROSPECTING

General Principle of Method Used

The self-potential electrical method is the simplest of the electrical geophysical prospecting methods and depends upon the production of a electrical potential difference during the oxidization of a sulphide ore body. It has long been known that the oxidizing upper part of an ore body has a negative potential relative to the lower part and that electrical currents flow inward and downward to the top of the ore body from the

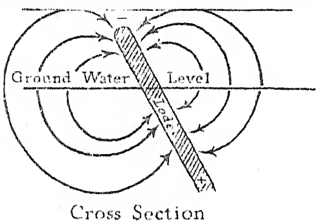


FIG. 3—Idealized cross section of an oxydizing sulphide lode showing electrical flow lines.

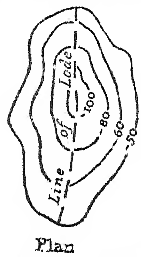


FIG. 4—Plan of surface potentials produced by electrical flow lines from sulphide lode.

ground above it. Observations made by test electrodes along the surface of the ground above such an ore-body will show a centre of negative potential above the body. Fig. 3 illustrates the flow of current in a cross section through a lode, and Fig. 4 the pattern of equipotential line above a lode.

The conditions around the ore-body are those of the normal electric cell and external conductor inverted, the ground surrounding the ore-body being the electrolite while the ore-body represents the internal conductor that completes the circuit. It must be expected that slight differences in rate of oxidation of the ore will cause considerable differences in potential, and, what is more important, that even if ore is present but not being oxidized then the self-potential method will fail to give results. Without considerable prior experience interpretation is difficult, for as with other geophysical methods the size of the anomaly depends both on the depth and quantity of ore.

Instrument

The potential differences were measured by a bridge-type millivoltmeter in which the difference in potential between the earth electrodes

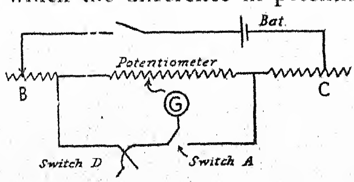


FIG. 5—Circuit of potentiometer.

is balanced against an equal potential difference taken from a potentiometer and derived from a $1\frac{1}{2}$ v. cell. The advantage of this method over

the direct measurements of voltage is that when the circuit is balanced no current flows from the earth electrodes and consequently that the ground potential is not disturbed during measurement. Fig. 5 is a circuit of the meter.

The millivoltmeter was frequently callibrated in the field by moving switch " A " to " test " and then adjusting resistances " B " and " C " so that the galvanometer deflection was 12 divisions when the millivolt indicator arm of the potentiometer was at 50. This was the least sensitive setting of the instrument and was well suited to conditions at Kawau, where the underlying sulphides caused a maximum potential difference between electrodes 60 feet apart of about 40 mv.

Earth contacts were through electrodes constructed from porous pots filled with a saturated solution of copper sulphate and connected to the meter by a terminal attached to a copper cylinder immersed in the solution. Copper sulphate seeps through the base of these pots and makes contact with the ground. The potentials produced by the contact of simple metallic electrodes with the soil make the use of the more complicated porous pot electrodes essential. At Kawau frequent rain before and during the investigation made it unnecessary to dampen the ground during observations, a good earth contact being usually obtained a few inches from the original ground surface.

Field Procedure

The millivoltmeter was first roughly levelled and the galvanometer clamp released with switch " A " on " check." The galvanometer needle was then adjusted to zero position by levelling the instrument. Switch " A " was then turned to " test " and the battery current switched on. If the wires are correctly attached to the porous pots and the pots in contact with the ground, the galvanometer circuit then flows through the ground and damps the galvanometer, the needle of which indicates the resistance in the circuit by its freedom while swinging.

The potential difference between the forward and rear electrodes is then measured by adjusting the potentiometer arm so that the galvanometer needle indicates zero, but if the forward potential is positive relative to the rear then it is necessary to reverse the input leads by the reversing switch " D." The potential difference is then indicated by the position of the millivoltmeter arm. After recording the reading, the galvanometer is clamped, the current switched off and the switch " A " turned to " check." The instrument is then shifted to the next station and the procedure repeated.

The porous pots were placed in holes that had been dug a few inches deep. Beyond this depth it was found that a variation in depth of hole usually made a little difference. To check errors caused by a difference in potential between the two electrodes it was found necessary to observe the lines in two directions, the reverse readings being taken immediately after the forward readings. The sign of the reverse readings is opposite to the forward readings and the sum of the two readings between the two porous pots. The following is an example of such readings:—

Forward readings	..	–7	38	–55	–8
Reverse readings	..	2	–44	51	3
Sum of readings	..	–5	–6	–4	–5

Mean 5, difference between porous pots 2.5 mv.

Survey Methods

The station positions were established during the electrical measurements by measuring the slope distances between stations with the 60 feet wire to connect the forward electrode to the instrument. The slope distances were reduced to the corresponding horizontal distances before plotting them, aneroid heights used in constructing the contours shown of Fig. 2 being used to effect this reduction. This method of surveying during electrical observations is satisfactory for grass and open scrub, but becomes difficult and inaccurate in thick scrub, where it would be better to cut the lines and to establish the stations before measuring their potential differences.

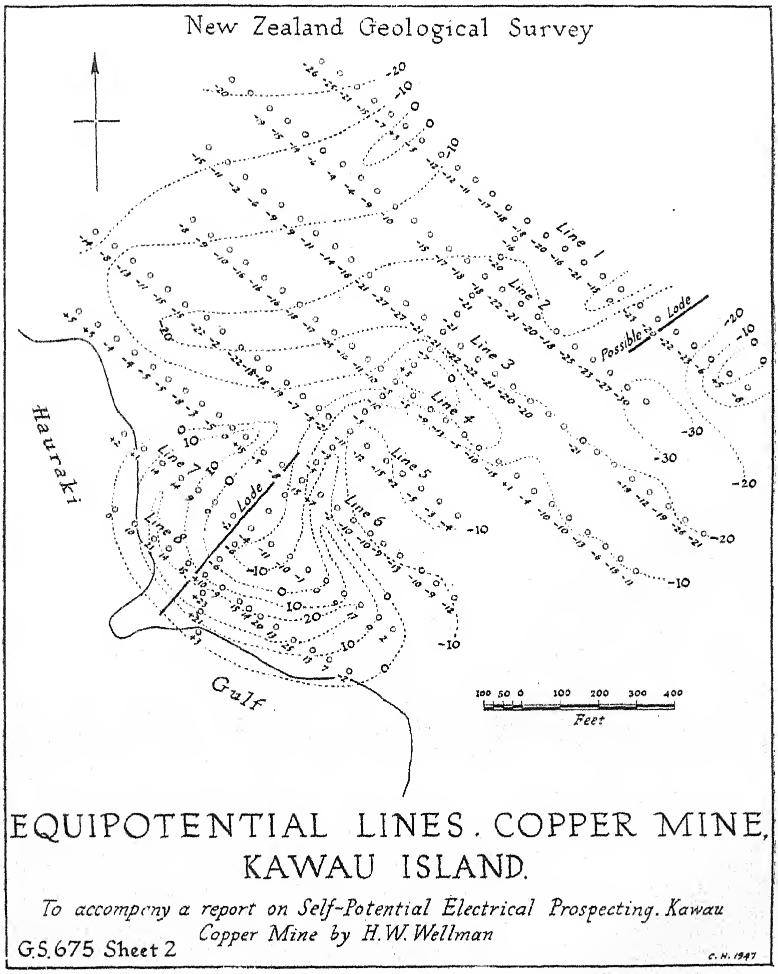


FIG. 6—(Caption on Map G.S.675, Sheet 2).

Graphical Representation of Results

The results of the observations are shown in Figs. 6 and 7 as potentials relative to the sea. These potentials were calculated for each station

by continuous addition of the observed corrected potential differences. The following is an example of such calculations:—

Station	0	1	2	3	4	5	6	7	8	9
Potential difference ..	2	−2	2	8	5	6	8	4	2	
Difference in potential between porous pot electrodes −2 mv.										
Corr. potential difference	0	−4	0	6	3	4	6	2	0	
Potential relative to station "O"	0	0	−4	−4	2	5	9	15	17	17

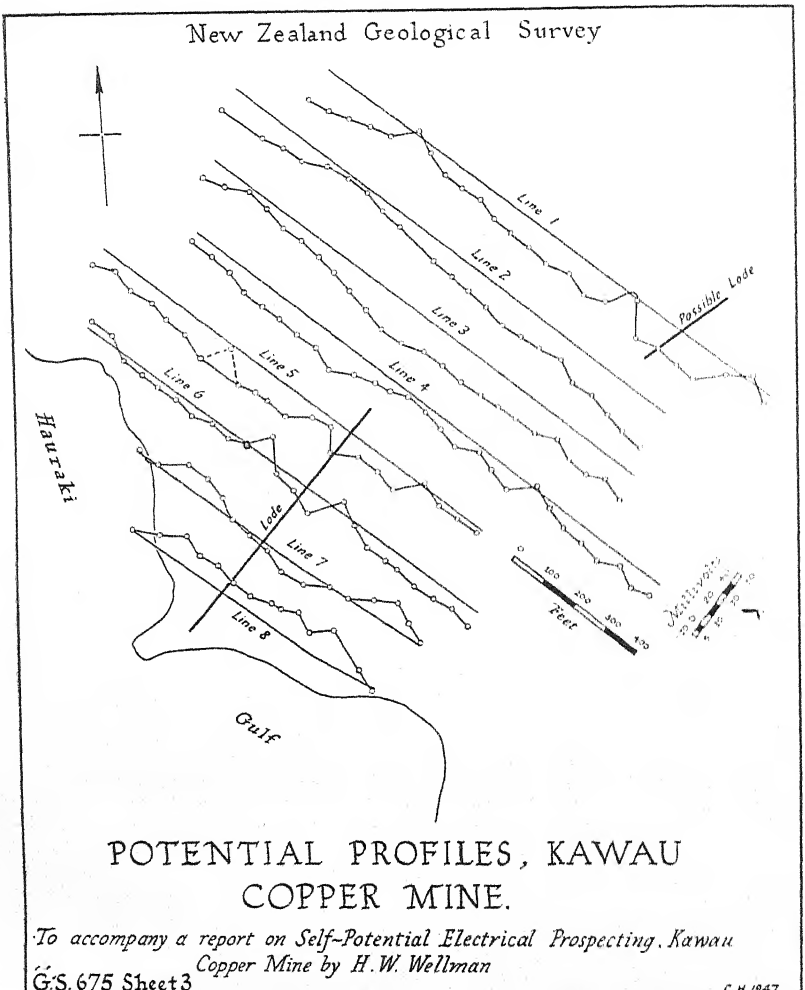


FIG. 7—(Caption on Map G.S.675, Sheet 3).

This method of continuous addition is subject to cumulative errors and in a more extensive survey it would be advisable to first establish control points by observing over longer intervals and then to adjust the values obtained from the shorter intervals to these. The two most

southerly survey lines are controlled by connecting both ends to the sea, taken as zero potential.

The potentials are shown (Fig. 6) as small figures close to the corresponding stations and from these values generalized equipotential lines have been drawn with a potential interval of 10 mv. These equipotential lines are only approximations to the true position of the lines which must be more sinuous than represented. Close to the sea the rise and fall of the tide must cause slight changes.

The same values are used in Fig. 7 to show the same variations in a different manner, the values being plotted normal to the line along which they were observed, positive above the line and negative values below, values considered due only to local superficial variations are connected by dotted lines.

Results of Observations

In both Figs. 6 and 7 the line of the lode is flanked by high values on lines 5, 6, 7, and 8, the area above the lode having lower values than normal. Anomalies along the line of the lode ceased at line 5 and if the lode continues past this line then oxidation is not sufficiently rapid to cause measurable potential differences. It is more probable, however, that the lode does not continue and that the old workings extended to the end of the lode.

The values at the eastern end of lines 2, 3, and 4, are small and erratic with little geological significance. Regular variations prevail along the western parts of lines 1, 2, 3, 4, and 5. These regular variations no doubt have some subsurface significance but are unlikely to be caused by underlying sulphides; they are more probably caused by the Tertiary-basement contact, though an almost complete lack of outcrops makes proof of this difficult.

The characteristic anomaly at the east end of line 1 probably indicates a sulphide lode and this interpretation is strengthened by the presence of a low ridge of manganese-stained jaspillite which crosses this line at the place where a disturbing feature would be expected. This ridge is about 10 feet wide and strikes north-east. No corresponding anomaly was found on line 2 and it is unlikely that there is a continuation in this direction. In the opposite direction, to the north-east, there are many outcrops of basement greywacke and argillite but no quartzite and the continuation of the lode is unlikely. Further electrical work in this district could well depend upon the results of testing this band of quartzite by drilling or trenching, and until this is done it did not seem worth while extending the observations into the scrub-covered areas where results can only be obtained with much greater difficulty.

The copper lodes at Copper Mine Point have been well prospected above sea-level and have been worked for an unknown but probably not great depth below sea-level. Any future prospecting would be most useful if it could test the quality of the ore well below the old workings, for then if the quality of the ore is too low to work the remaining upper unworked part would hardly be worth exploring.

No new information was obtained with regard to the west lode which extends beneath the sea to the south-west of Copper Mine Point, but the anomalies caused by the east lode have their maximum width at line 7 and do not extend beyond line 5. If it is considered that conditions were good enough when the mine closed down to warrant further prospecting, then it is suggested that the eastern lode could be tested at

600 feet below sea-level beneath line 5, by drilling at an angle of 30° from the vertical to the north-east from a point about 100 feet from the mouth of a small creek situated 700 feet east of the old mine chimney. The hole would probably cross the lode at an angle of 45° at 650 feet from the surface, if the lode continued to dip to the south-east at 75° as at the surface.

No difficulty would be experienced in landing the drilling gear from a scow to any point near the Copper Mine during normal weather; difficulty would, however, be experienced in obtaining water for drilling from the streams which normally carry little water.

CONCLUSIONS

The electrical work shows that it is possible to trace sulphide lodes by the self-potential method under the conditions that prevail at Kawau. The work is comparatively rapid as it is possible to observe about 100 stations a day if the area has been previously surveyed and pegged. Total interpretation of the results is difficult and where possible anomalies should be investigated during the electrical work so that full advantage can be taken of information obtained. It is essential that the observed lines be so close that anomalies can be correlated with certainty from line to line; a distance of not less than 200 feet appears suitable. The distance between stations along the lines has to be such that critical potentials are not skipped, and will depend upon the width and depth of lodes. At Kawau the distance could probably have been increased to 100 feet with advantage.

Topography appears to have no serious effect on the potential distribution but must cause some modificaton where the slopes exceed 30°. The following disturbing features may cause difficulties unless recognized in the field:—

(1) A gradually changing difference in potential between electrodes that causes a gradual rise or fall in the potential values. This could possibly be reduced if the electrodes were constructed with greater care, but it is probable that the establishment of control points at say ten chain intervals would be the most satisfactory solution.

(2) Positive anomalies of superficial origin. These anomalies, the cause of which is uncertain, appear to be associated with areas of dry subsoil caused by slips. The largest potential difference caused by these features was 50 mv., extended over a width of 30 feet and had a length of 60 feet (Fig. 8). Observations made in a trench cut across the line of anomaly showed that it was a superficial feature and extended down only a few feet from the surface.

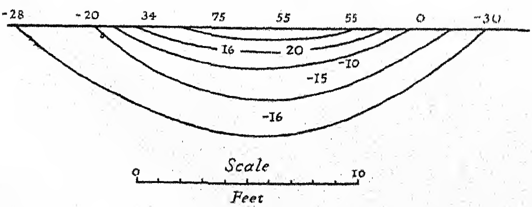


FIG. 8—Cross section showing electrical potential distribution in a shallow trench cut through a superficial anomaly.

(3) Tree roots and trees. Fig. 9 shows the potential variations in the vicinity of a pohutukawa tree; similar variations were observed close to all large trees. It will be seen that the effects are small unless contact is made with large tree roots, small rootlets apparently having little effect.

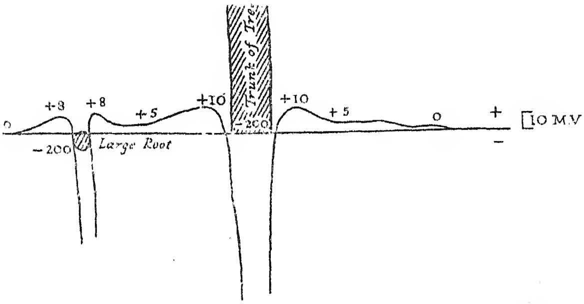


FIG. 9—Potential variations near a large pohutukawa tree.

REFERENCES

COX, S. H. (1882): *Rept. Geol. Explor. during 1881. No. 14.*

FERRAR, H. T. (1934): The Geology of the Dargaville-Rodney Subdivision. *N.Z. Geol. Surv. Bull. 34.*

HECTOR, J. (1868): *Rept. Geol. Explor. during 1868-69. No. 5.*

HENDERSON, J. (1939): *N.Z. J. Sci. and Tech., XX,* 177B-81B.

EUPTEROMALUS SP. AS A HYPERPARASITE

SOME INDICATION OF ITS INFLUENCE ON THE ESTABLISHMENT OF *ANGITIA CEROPHAGA* IN NEW ZEALAND

By PHYLLIS L. ROBERTSON, Entomology Division, Plant Research Bureau, Department of Scientific and Industrial Research, Nelson

(*Received for publication, 29th July, 1947*)

Summary

1. An outline is given of the history of the chalcid hyperparasite *Eupteromalus* sp. in relation to primary parasites of the diamond-back moth and white butterfly.

2. Figures are quoted to illustrate that it was largely responsible for the heavy mortality which occurred during the attempt to mass breed the diamond-back moth larval parasite, *Angitia cerophaga*, in field cages.

3. Its apparent inability to destroy *A. cerophaga* completely in the field is discussed and illustrated by records.

INTRODUCTION

HYPERPARASITISM is a factor of importance in many aspects of biological control investigations. First, it enters into the complex studied in the country of origin, when determining the parasite species, or group of species, most suitable for utilization overseas as a controlling agent. Some investigators have stressed the importance of choosing for introduction parasite species which suffer little from hyperparasitism in their native habitat. Secondly, in obtaining and shipping supplies of primary parasites, consideration has to be given to the problem of whether or not consignments should include any such hyperparasites as normally attack them. Wardle and Buckle (1923) say of this: " It is doubtful whether any greater efficacy in action of introduced parasites is to be obtained by preventing the introduction of their hyperparasites." The view more generally subscribed to, nevertheless, is that the elimination of hyperparasites is simply effected, and is more likely to increase than reduce the efficiency of introduced parasites. It is, however, during the actual establishment of introduced parasites in their new habitat that hyperparasitism may assume a role of prime importance. Numerous writers have emphasized the fact that, while associated hyperparasites from the place of origin may be excluded in any parasite introduction, or a parasite be chosen which is normally free from hyperparasitism, it is impossible to ensure against its being attacked by hyperparasites already present in the new environment. Imms (1937) states: " Hyperparasites in general are far less restricted in their host-selection than most Hymenopterous primary parasites. They are able to adapt themselves to a wider range of hosts, especially in the absence of preferred species—a trait which explains the heavy attacks certain introduced primary parasites undergo in countries where the normal and regular hyperparasites are absent." The introduction into New Zealand of the European parasite *Angitia cerophaga* against the diamond-back moth has provided a striking example of such an occurrence. A chalcid hyperparasite of the genus *Eupteromalus,* already known to be present in this country, reduced the initial, concentrated field colonies so severely as apparently to jeopardize the whole undertaking.

The conflicting ideas contained in the literature on the significance of hyperparasitism suggest that it has seldom been intensively studied. Nevertheless, instances in which hyperparasites have been known to be responsible for heavy reduction in populations of beneficial primaries are sufficiently numerous to warrant the conclusion that any additional records, however incomplete, may be of value to the understanding of the natural complex established by parasite introduction. It is on this ground that the following notes on the hyperparasite *Eupteromalus* sp. are presented. The general information on its incidence on primary parasites in this country is fragmentary, while the attempt to make a numerical estimate of the extent of the initial attack of *Eupteromalus* on *Angitia cerophaga* provides no more than an indication of its relationship to the diamond-back moth complex. The records on which this paper is based were collected by the writer in the 1936-37 and 1937-38 seasons and were incidental to the large-scale breeding and field distribution of *Angitia cerophaga*, being carried out by members of the Entomology Division under Mr. J. Muggeridge, at that time Associate Director.

HISTORY OF EUPTEROMALUS SP. IN NEW ZEALAND

Attention was first drawn to *Eupteromalus* in 1934, when Mr. Muggeridge bred this chalcid hyperparasite from cocoons of the European strain of *Apanteles glomeratus*, which was then being liberated in New Zealand against the white butterfly (*Pieris rapae L.*). Specimens were sent to Sir Guy Marshall, Director, Imperial Institute of Entomology, and his comments were as follows:—

"Dr. Ferriere . . . says that it is a species of *Eupteromalus* (family Pteromalidæ) which is closely allied to *E. nidulans*, Först., a common species which is apparently different from it. He says that unfortunately he is unable to state whether this is really a European species or one that is indigenous or already introduced into New Zealand. It does not appear to agree with the descriptions of any of the other European species known to him, and at the same time the genus has not so far been recorded from either New Zealand or Australia."

It is clear from the above that, while there is a possibility of the hyperparasite's being indigenous to New Zealand, this is by no means certain—a point which has become obscured in recent years.

In 1934 also, Dr. W. Cottier, Plant Diseases Division, made some laboratory observations on *Eupteromalus*. He recorded breeding through one generation of the hyperparasite in pupæ of *Pieris rapae* parasitized by *Pteromalus puparum*, the first emergence of adults being on the 7th August of that year.

In December, 1936, it was first recognized that secondary parasitism might have a serious effect on parasite introductions against the diamond-back moth. At this period a commencement had been made on the attempt to control *Plutella maculipennis* by biological means, large consignments of the ichneumonid primaries, *Angitia cerophaga* and *A. fenestralis* (two supposed species whose identity was later lost through interbreeding) having been imported from England through the Imperial Institute of Entomology. The New Zealand Entomology Division built up stocks of these *Angitia* through laboratory breeding and subsequently initiated field colonies in Hawke's Bay by mass rearing in field cages of the type described by Muggeridge (1942-43). These cages were enclosed

by carcase-cloth, an open-mesh material which did not exclude such minute insects as chalcids. It was soon found that large colonies of hyperparasites developed at the expense of the introduced parasites being reared. The Imperial Institute of Entomology confirmed the suspicion that the hyperparasite involved was the same species of *Eupteromalus* as that previously bred from *Apanteles glomeratus*.

In January, 1937, the writer continued Dr. Cottier's 1934 observations on *Eupteromalus* as a hyperparasite of *Pieris rapae*. One generation of *Eupteromalus* was successfully bred through in the laboratory on *Pteromalus puparum* parasitizing *Pieris* chrysalids. It was found, however, that *Eupteromalus* could not compete with *Pteromalus* in the numbers produced per chrysalid, so that it was not likely to reduce the efficiency of *Pteromalus* in the field to any appreciable extent. In a further series of laboratory experiments made at this time, *Eupteromalus* was tested as a primary parasite of both the white butterfly and the diamond-back moth. In a number of cases the pupæ exposed appeared to be killed by ovipositor punctures, but oviposition did not occur. Up to the present the *Eupteromalus* sp. in New Zealand has not been recorded as a primary, in contrast to the known habits of *Eupteromalus nidulans*, the species to which, according to Ferriere, it is probably most closely allied. The history of *E. nidulans* in the United States, acting as both a primary parasite and a hyperparasite, has been traced by Proper (1931). He states that *E. nidulans* was first imported from Europe in 1905 as a primary parasite of the brown-tail moth. After establishment, it was found also to occur as a hyperparasite on one of the brown-tail moth larval primaries, *Apanteles lacteicolor*. Later again, it became known as a useful primary parasite of the satin moth, after this pest had spread through Massachusetts in 1920. The *Eupteromalus* in New Zealand, on the other hand, has been recorded only from parasitic, hymenopteron hosts and has not up to the present being induced to attack Lepidoptera directly.

It was not until the 1936-37 summer season that *Eupteromalus* sp. was recorded as a secondary parasite on the *Angitia* known to attack *Plutella* in New Zealand prior to the introduction of *A. cerophaga*. The negligible degree of hyperparasitism in the New Zealand species has already been referred to by the writer (1939).

In 1938, during the first year of introduction of *Diadromus collaris* against the diamond-back moth, Mr. B. B. Given, Entomology Division, found the species to be attacked by *Eupteromalus*, although only to a minor degree.

Recent examination of cocoons of the American strain of *Apanteles glomeratus*, referred to by Muggeridge (1942-43) as having been successfully established in the Nelson district, has shown this also to be attacked by *Eupteromalus*.

Thus already *Eupteromalus* has been recorded from quite a wide range of beneficial insects in New Zealand, its known hosts including: the white butterfly larval parasite *Apanteles glomeratus*, family Braconidæ, of both the European and American strains, which are generally considered distinct biological races; the white butterfly pupal parasite, *Pteromalus puparum*, family Pteromalidæ; the diamond back moth larval parasites *Angitia cerophaga* and *Angitia* sp. (N.Z.), family Ichneumonidæ; and the diamond-back moth pupal parasite, *Diadromus collaris*, also family Ichneumonidæ. These observations have been made only incidentally during recent economic investigations, so that the host range

of *Eupteromalus* sp. may possibly be much more extensive and it may have to be considered as a factor in any future biological control projects undertaken in New Zealand.

EUPTEROMALUS SP. AS A HYPERPARASITE ON ANGITIA CEROPHAGA

1936-37 Records

Mention has been made in the previous section of the Entomology Division's attempt, during this season, to rear *Angitia cerophaga* in field cages in Hawke's Bay, where *Plutella* outbreaks in crucifers then reached epidemic proportions each summer. It was considered by Mr. Muggeridge that large colonies of the parasite could be most rapidly built up for field distribution by this method. Plants in the field were caged and heavily infested with *Plutella* prior to the introduction of adults of *Angitia cerophaga* bred in the laboratory. The bulk of parasite pupæ reared were later collected from the cages and sent back to the laboratory at Nelson, where they were placed in emergence cans. In early December, 1936, several chalcids were reared from the first field-bred *Angitia* pupæ received from Hawke's Bay. Altogether 2,578 pupæ were produced from the first set of field cages, but the emergence of adult *Angitia* from them was disappointingly small. Large numbers of chalcids were produced, but these did not give an accurate index to the number of *Angitia* pupæ hyperparasitized.

Firstly, superparasitism was common, up to three adult chalcids being reared from one *Angitia* pupa. Secondly, a considerable number of eggs, larvæ and pupæ of the hyperparasite did not complete development, so that there could be no evidence of hyperparasitism without dissection. Accordingly, during the 1936-37 summer, sets of samples from several batches of pupæ received in the laboratory from Hawke's Bay were dissected, and on these samples the numbers hyperparasitized were estimated. The following table shows the results obtained:—

TABLE I. HYPERPARASITISM IN FIELD CAGES, 1936-37

Date *Angitia* pupae collected	No. of pupae	No. of adult *Angitia* reared	Total No. of pupae failing to complete development	No. of adult *Eupteromalus* emerging	Total No. of pupae hyperparasitized — *from dissection*
10/12/36-5/1/37	2578	352	2226	1020	1676
18-29/12/36	222	3	219	96	189
5-8/1/37	3807	115	3692	717	2608
2-4/2/37	739	72	667	210	473
9-11/2/37	2359	470	1889	521	1361

Fig. 1 illustrates the end result of rearing the third batch of pupæ (5-8/1/37) to maturity. Here only 3 per cent. of the pupæ produced adult *Angitia cerophaga*, making field cage breeding impossible under such conditions. Of the remaining 97 per cent., dissection showed 68.5 per cent. to be hyperparasitized, although only 18.8 per cent. produced adult hyperparasites. The disparity between the two latter figures, in every case in which dissections were made, demonstrated the necessity for basing all future hyperparasitism records on dissections.

From both Table I and Fig. 1, it seems obvious that, in the 1936-37 season, the failure of the majority of field-cage pupæ to complete development was due, in the main, to the activity of *Eupteromalus* sp.,

the residual mortality being no more than could have been expected in any mass-breeding project. At this time, however, no evidence could be produced of the possible effect of hyperparasitism on field populations of *Angitia*.

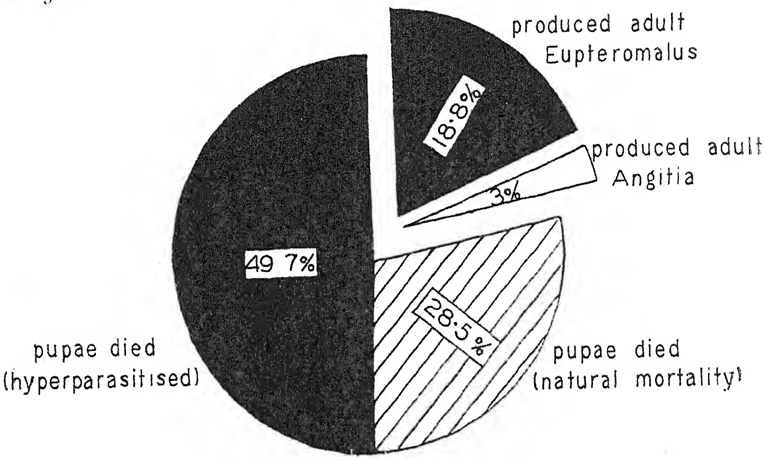


FIG. 1
Analysis of *Angitia* pupæ collected from field cages from 5th to 8th January, 1937

1937-38 Records

During this season the Entomology Division made a further attempt to breed *Angitia cerophaga* in field cages, this time in Nelson, where there was a possibility that *Eupteromalus* sp. might not be capable of such rapid increase as in Hawke's Bay. Breeding was commenced early in the summer, the first pupæ being collected in the second week in November. For this week, pupæ produced from field cages totalled 4,561, and from these 3,151 *A. cerophaga* adults were reared with only 16 hyperparasites. This was in marked contrast to the initial results from Hawke's Bay in the previous summer. Field cage breeding was continued until February, but as the season advanced hyperparasitism increased, and was accompanied by an increase in the proportion of pupæ which failed to complete development. The end result was little better than that produced in Hawke's Bay.

Throughout this period of field-cage breeding a series of samples was dissected from the pupæ collected each week. From this a record was compiled of the changes through the season in the total percentage of pupæ which failed to complete development, and the percentage which were killed by hyperparasitism. Fig. 2 shows the trends which were demonstrated. The total mortality rose steadily from 30.9 per cent. in early November to 94.5 per cent. in February. At the same time hyperparasitism increased from 1.5 per cent. in November to 42 per cent. in February. The points are plotted according to the logarithmic scale, so that comparative rates of increase are illustrated by the slopes of the lines. Fig. 2 shows that the rate of increase in hyperparasitism was very rapid at the beginning of the season and did not agree closely with the increase in mortality. Later, however, the two factors were more obviously related in the course they followed. It is apparent that hyperparasitism was the factor chiefly responsible for increasing the mortality of field-cage pupæ from the normally expected 30-40 per cent. to the

excessive amount of 90-95 per cent. It is also clear that the initial, accelerated rate of increase in hyperparasitism was unduly favoured by the aggregation of *Angitia cerophaga* pupæ in field cages.

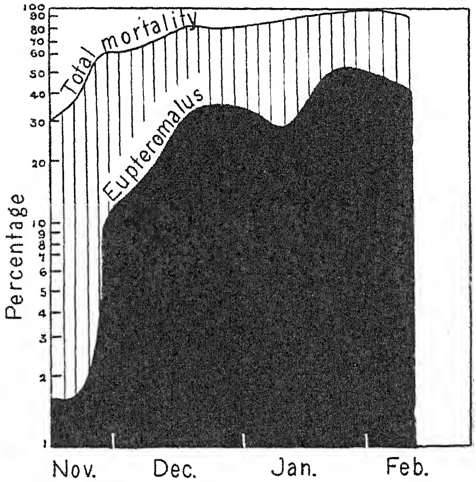


Fig. 2

Hyperparasitism by *Eupteromalus* as a factor in the total mortality of *Angitia* pupæ produced in field cages. 1937-38

In conjunction with parasite breeding the Entomolgy Division, in 1937-38, carried out field surveys in Nelson and its surrounding districts, as a check on the establishment of *Angitia cerophaga*. Samples from all these field collections were dissected by the writer, in the hope of gaining from them some indication of the inter-relationship of primary and secondary parasitism in the field. The most complete records were obtained from the experimental area at Cawthron Institute, where collections were made once or twice a week from December, 1937, to the end of March, 1938. This area was adjacent to the field cage experi-

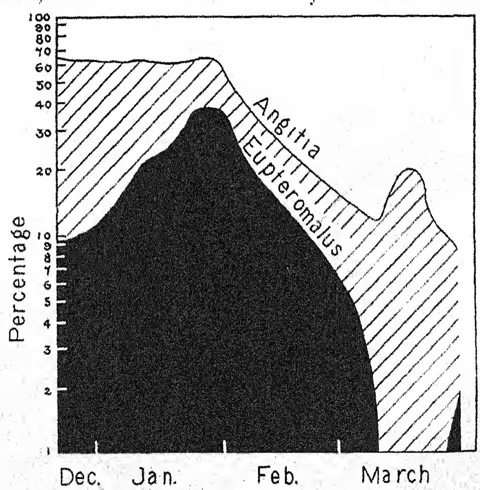


Fig. 3

Eupteromalus and *Angitia* on diamond-back moth in the field Cawthron area, Nelson. 1937-38

ments and, as a result, *Plutella* populations in it reached a high density at the beginning of the season. Early liberations of the introduced *Angitia* were made here, and initial populations were continually being augmented from the field cages.

Fig. 3 illustrates the course of primary and secondary parasitism recorded during the summer. At this time field collections were being made in bulk, so that there was no basis for the assessment of variations in the host population. In Fig. 3 primary parasitism by *Angitia* and hyperparasitism by *Eupteromalus* sp. are both expressed as percentages of the total number of *Plutella* pupæ collected. The region bounded by the lower line thus indicates the proportion of the introduced parasite population killed by hyperparasitism. Logarithmic intervals are used in the graph, and the curves have been smoothed, so that comparative rates of increase and decrease can be more readily followed.

Eupteromalus reached a maximum and produced a marked and sudden drop in the *Angitia* population. Both *Angitia* and *Eupteromalus* continued to decrease for some weeks, but the rate of decrease of the hyperparasite was so much more rapid that, by the middle of March, it had virtually ceased its attack on the *Angitia* population remaining. At the end of the season *Angitia* was again able to increase slightly, although this was followed by a reappearance of hyperparasitism.

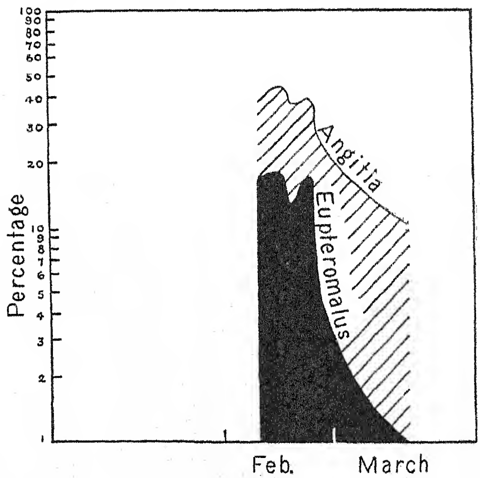


FIG. 4

Eupteromalus and *Angitia* on diamond-back moth in the field
Town area, Nelson, 1937-38

Primary parasitism had reached a high level when sampling was commenced, and this was maintained during December and January. It appears that secondary parasitism only began to increase after the establishment of this high level. By the end of January the effect of

Collections during February and March in the Nelson town area (remote from Cawthron) produced the results shown in Fig. 4. Here both primary and secondary parasitism had already reached, or passed, their maximum points and continued to fall until the middle of March. At this period, as in the previous case, hyperparasites ceased operating, but a residual population of primaries continued to attack the diamond-back moth.

On the Waimea Plains (see Fig. 5) *Plutella* populations were not heavy and primary parasitism did not reached a high level. There was no more than a trace of hyperparasitism at the beginning of February, and it was obvious that, at such population levels, hyperparasitism was a negligible factor.

These diamond-back moth surveys, carried out at the Cawthron Experimental Area, the Nelson town area and on the Waimea Plains in the season immediately following the introduction of *Angitia cerophaga*, gave an indication of the nature of the interaction of this primary parasite with the hyperparasite *Eupteromalus* sp. in the field. Records from the three localities all followed the same trend, demonstrated most clearly in Fig. 3. Here, as was to be expected, parasitism curves for both species rose from a low level at the beginning of the summer, reached a peak about January or February and again decreased markedly in the autumn. The greatest significance, however, lay in the relative rates of increase and decrease of *Angitia* and *Eupteromalus*. The curve followed by *Eupteromalus* both rose and fell much more sharply than that of *Angitia*. Thus, while *Eupteromalus* increased rapidly to signifi-

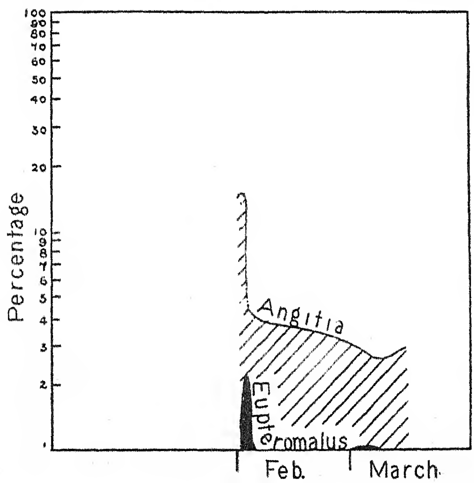


FIG. 5

Eupteromalus and *Angitia* on diamond-back moth in the field Richmond. 1937-38

cant proportions after the establishment of a high population density of *Angitia*, its attack virtually ceased as soon as the *Angitia* density was reduced (as in Fig. 5). Moreover, even at the peak of hyperparasitism, under conditions which appeared to be optimum, *Eupteromalus* did not totally destroy the *Angitia* population. The first season's field records therefore suggest that the activity of the hyperparasite *Eupteromalus* sp. could not, of itself, completely nullify the attempt to establish *Angitia cerophaga* in New Zealand, despite its devastating attack on the artificially concentrated field colonies. These records, however, do not demonstrate the ultimate effect of the part-destruction of concentrated *Angitia* populations on the biological control of the diamond-back moth. From the residual *Angitia* population, which remains to attack *Plutella* even after the most severe reduction by hyperparasitism, it may be inferred that *Angitia* retains some value as a primary parasite. Later

field observations by Mr. Muggeridge suggest that this value is high. However, it remains for investigations which have been planned for the future to correlate directly the interaction of primary and secondary parasitism with the present population level of the diamond-back moth.

REFERENCES

BODENHEIMER, F. S. (1938): "Problems of Animal Ecology." Oxford University Press.

GAUSE, G. F. (1934): "The struggle for existence." The Williams and Wilkins Company, Baltimore.

HOWARD, L. O. and FISKE, W. F. (1912): The importation into the United States of the parasites of the gipsy moth and the brown-tail moth. *U.S. Bur. Ent. Bull. 91.*

IMMS, A. D. (1937): "Recent advances in entomology." J. and A. Churchill Ltd., London. 2nd Ed.

KURDJUMOV, N. (1913): Notes on Pteromalidæ (Hymenoptera, Chalcidodea). *Rev. russe Ent., 13,* 1-24.

MUESEBECK, C. F. W., and DOHANIAN, S. M. (1927): A study in hyperparasitism, with particular reference to the parasites of *Apanteles melanoscelus* (Ratzeburg). *U.S. Dept. Agr. Bull. 1487.*

MUGGERIDGE, J. (1942-43): The White Butterfly (*Pieris rapae* L.). *N.Z. J. Sci. and Tech., 24 (Sec. A),* 107-29; *25 (Sec. A),* 1-30.

PARKER, H. L. (1924): Recherches sur les formes post-embryonnaires des Chalcidiens. *Ann. Soc. ent. France, 93,* 261-379.

PROPER, A. B. (1931): *Eupteromalus nidulans,* a parasite of the brown-tail and satin moths. *J. Agr. Res., 43,* 37-56.

—— (1934): Hyperparasitism in the case of some introduced lepidopterous tree defoliators. *J. Agr. Res., 48,* 359-76.

ROBERTSON, PHYLLIS L. (1939): Diamond-back moth investigation in New Zealand. *N.Z. J. Sci. and Tech., 20,* 330A-64A.

TAYLOR, T. H. C. (1937): "The biological control of an insect pest in Fiji." Imp. Inst. Ent., London.

WARDLE, R. A., and BUCKLE, P. (1923): "The Principles of Insect Control." Longmans, Green and Co., Manchester.

WOODRUFF, L. C. (1939): An analysis of insect growth curves. *J. N.Y. Ent. Soc., 47,* 47-55.

ON THE OCCURRENCE OF NATURAL ARTESIAN SPRINGS IN THE HOROWHENUA DISTRICT

By G. Leslie Adkin, 156 The Terrace, Wellington

(Read before Section E, Royal Society of New Zealand Science Congress, 22nd May, 1947)

(*Received for publication, 6th June, 1947*)

Summary

A description is given of the topographic and geomorphic features of the locality in which three groups of springs, rising to the surface under hydrostatic pressure, occur. Details of the distribution and surface features of the springs are given. The relationship of the underlying post-Tertiary formations from which the spring water is derived is dealt with. Satisfactory evidence of the mode of origin of the individually restricted conduits through which the spring water reaches the surface has not been obtained.

A number of springs of the unusual type specified occur in the Horowhenua district on the floodplain of the Koputaroa Stream. The locality is in the vicinity of the Koputaroa railway-station, on the Levin—Palmerston North section of the Main Trunk line, 65 miles north of Wellington City (see Fig. 1). The Koputaroa is a minor left-bank tributary joining the canal-like lower course of the Manawatu River. The Koputaroa rises in close proximity to the debrochure of the Ohau River, its most southerly source being on the western side of the extreme southerly end of the Arapaepae Ridge of the Tararua western foothills. From this point the stream flows for eight miles, obliquely across the Horowhenua lowland, to join the Manawatu River, eleven miles inland (by air line) from the coast.

Along its lower reaches the Manawatu pursues a well-developed meandering course consequent on a very low gradient, the channel being tidal for many miles upstream from its mouth. A feature of this part of its course is the raised silt banks forming natural levees—firm dry ground, matching the curves of the channel, from five to fifteen chains in width. Formerly, these levee-like banks tended to impound the tributary drainage (on both sides of the river) to form extensive marginal swamps.

In common with most of the other tributaries along the lower course of the main river, the floodplain of the Koputaroa Stream was masked except for similar though smaller levee-like banks fringing its channel, by deep swamp bearing a dense growth of moisture-loving vegetation, including stretches of kahikatea forest. In the case of the Koputaroa, the floodplain swamp conditions originally extended upstream for a distance of four miles to a point a little more than a mile above the position of Koputaroa railway-station.

Drainage operations carried out in recent years under modern farm development, having for their objective the production of increased pasturage for livestock, have banished the former swampy condition of the Koputaroa floodplain to a line a mile and a half downstream from its former limit; it is on this reclaimed area that the presence of natural artesian springs, the subject of this paper, has been revealed.

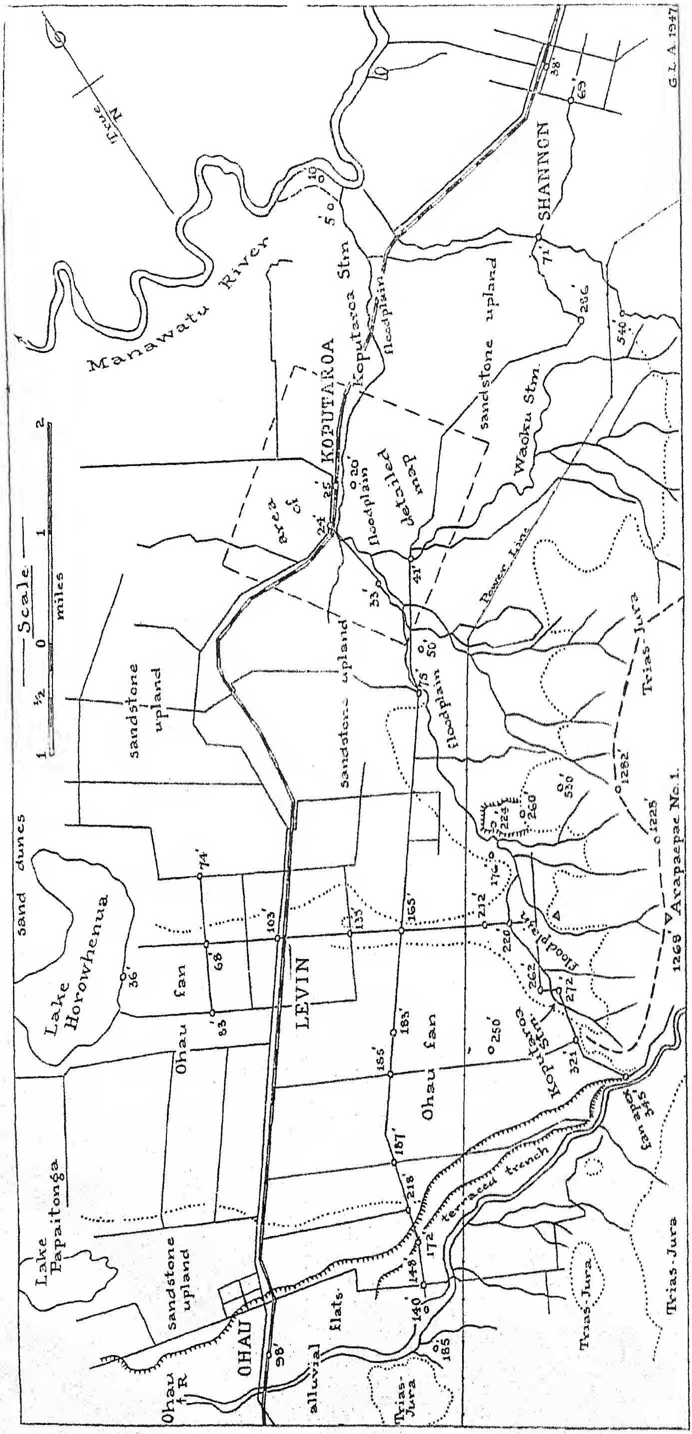

True N
Manawatu River
Scale
miles
KOPUTAROA
Koputaroa Stm
floodplain
area of detailed map
SHANNON
sandstone upland
Waoku Stm
Power Line
Trias-Jura
Arapaepae No. 1
sand dunes
Lake Horowhenua
Ohau fan
LEVIN
Lake Papaitonga
terraced trench
fan apex
OHAU
Ohau R
alluvial flats
G. L. A. 1947

Fig. 1

The artesian-type springs of the area occur as three groups: the first, numbering approximately three units, is located 80 chains upstream from our adopted datum point, the Koputaroa railway-station; the second, numbering twelve units, is 63 chains upstream; and the third, the principal group and the one more particularly studied, numbering 34 units, lies directly across the floodplain from the railway-station and 18·45 chains distant. A few other isolated but powerful springs occur downstream from the third group and there is reason to believe, from information supplied by local settlers, that other groups or units occur in the still undrained swamp masking the Koputaroa floodplain farther downstream (Fig. 2).

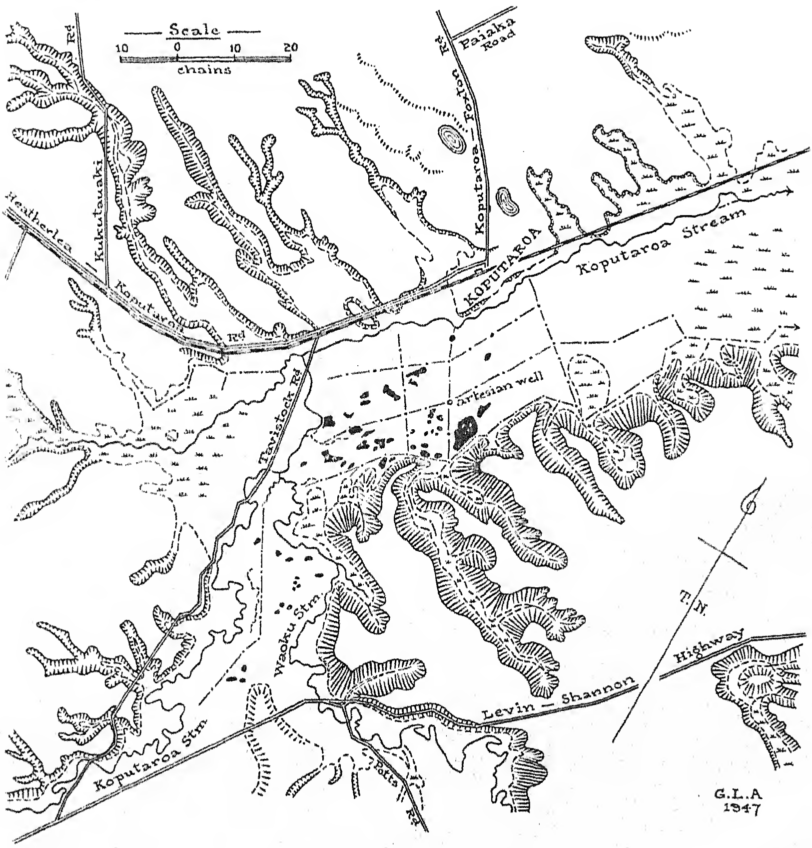


Fig. 2

Confining attention to the three groups of springs in the artificially drained area, the fact that these are of progressively increasing number and volume of flow in a linear direction down-stream is in keeping with their relatively deep-seated source and high-pressure condition as compared with springs of more normal types. Since the drainage of the floodplain, which has resulted in the settlement and consolidation of its general surface, the efflux of each of the individual springs stands out as a flattened dome-like mound up to 2 ft. 6 in. in height; the margins of these are usually well-defined and rather abrupt. In diameter

the mounds vary from a minimum of a few yards up to 40 or 50 yards, with one mound of twice the latter diameter. The areal extent of each mound appears to be controlled principally by the individual volume of ascending water and to a lesser degree by conditions favouring or hindering the flowing away of the water discharged from the vent or spring-head. The material of the mounds appears to be similar to that of the floodplain itself except at the centres where silts and mud from below are buoyed up in an extremely fluid condition where the conduit carrying the uprising waters reaches the surface; the remainder of each mound is crusted over by a more or less continuous turf, the whole quivering underfoot to an increasing degree as the dangerously unstable centre is approached. It should here be stated that the artesian character of these springs has been amply demonstrated by the effects of sinking a pipe at one of them. The natural vent dried up and the pipe discharged, from a depth of 28 feet, a good flow of the clear, sparkling water characteristic of artesian wells of moderate depth, the water rising to a height of approximately two feet above the general ground-level.

An additional point may be noted before turning to a consideration of the source and origin of these springs. A significant feature—indicative of their relatively deep-seated source by reason of which they reach the surface under marked hydrostatic pressure—is their independence of the surface drainage. Several of the spring-heads reach the surface in quite close proximity to the stream-channel—one, indeed, on its very brink—the upflowing waters rising eight to ten feet above the stream water-level instead of seeping laterally to it in the manner normal to ordinary ground-water.

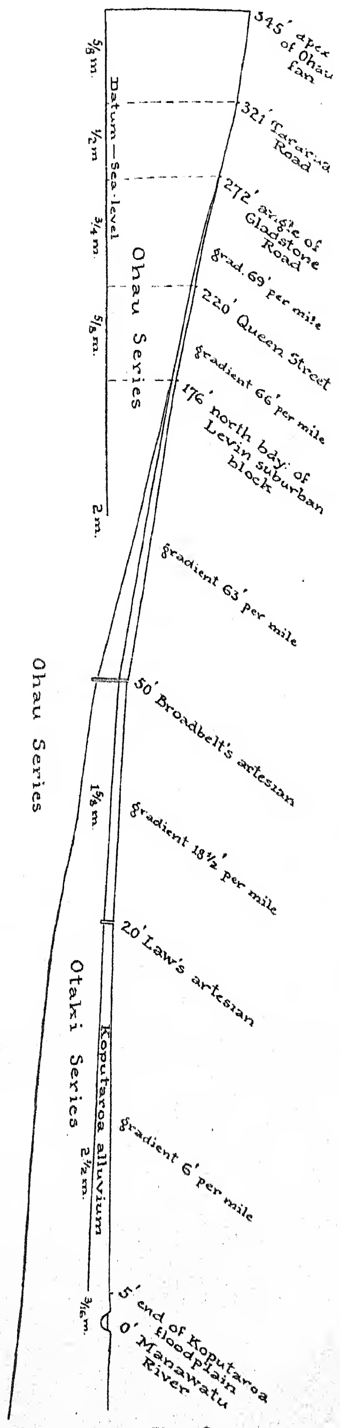
ORIGIN OF SPRINGS

In discussing the origin of the Koputaroa artesian-type springs it will be necessary to review briefly the relevant salient features and structure of the geological formations of the terrain in which they occur. The basement rocks of the area are the Trias-Jura (?) greywacke-argillite series of the Tararua Range; these form the 'old land' of the area and extend westward at depth under the fringing lowland strip.

The lowest member of the Quaternary formations of the lowland belt is the older piedmont fluviatile deposit extending from Waikanae to the Rangitikei River—coalescent major fans of the present rivers (a series of about eight), referable to the later part of the Early Pleistocene. A suitable local formation-name would be Ohau Series, the maximum thickness disclosed to date being 530 feet in the Ohau fan at a point about 70 feet above sea level and four and a half miles down-slope from the fan apex (altitude 345 feet).

The next formation is that which originated as the Horowhenua coastal plain—sandstone and consolidated silts, predominantly marine—and known as the Otaki Series, though surviving to only a minor extent in the Otaki area, is well-developed and preserved in central and northern Horowhenua County and northwards towards Wanganui. It overlies the major fans, attaining its maximum thickness at their coalescences and thinning towards their respective apices. The age, on diastrophic grounds, is approximately Later Pleistocene to Recent.

Overlying the lowered and dissected surface of the Otaki Series is a minor formation of Recent age comprising the floodplain and irregular fan-like deposits of minor water-courses rising in the Tararua foothills and debouching on or crossing the lowland area.



345' apex of Ohau fan
321' Tararua Road
272' angle of Gladstone Road
grad. 69' per mile
220' Queen Street
gradient 66' per mile
176' north bdy. of Levin suburban block
gradient 63' per mile
50' Broadbelt's artesian
gradient 18½' per mile
20' Law's artesian
gradient 6' per mile
5' end of Koputaroa floodplain
0' Manawatu River
5/8 m.
1/2 m.
3/4 m.
5/8 m.
2 m.
1⅝ m.
2½ m.
3/16 m.
Datum—Sea-level
Ohau Series
Ohau Series
Otaki Series
Koputaroa alluvium

FIG. 3

The remaining formation of the district—though not relevant to the present discussion—is the coastal aeolian belt, extending from Paekakariki to Wanganui. This has not received a local formation-name, and to supply a need, Himatangi Series is suggested, the maximum width of the belt (eleven miles) being attained at the original Himatangi site near Rangiotu.

Reference to the section, Fig. 3, will make clear the succession and relationship of the relevant members of the foregoing formations along a line from the Ohau debouchure to the Manawatu River—a line approximately coincident with the course of the Koputaroa Stream. The levels and contacts are carefully plotted, using all available data. There is sufficient evidence that the depositional dip of the surface of the Ohau fan varies more or less rythmically in a radial direction. Hence a curve representing that surface changes from convexity immediately below the fan apex to concavity farther down the slope with considerable flattening towards the periphery. This major reversed curvature is diversified by minor rhythmic undulations. The basal portion of the Otaki sandstone appears to have been deposited on the fan surface during a period of secular subsidence under conditions which did not permit any appreciable modification of the fan surface (unless it can be proved that the minor undulations mentioned above are due to successive incipient planations repeatedly interrupted by continued subsidence, instead of being due to depositional limitations during the final stages of the building of the fan, as suggested by the present writer, in an earlier paper (1911)). Along the line of the section given, the coastal plain surface originally varied from about 500 feet above present sea-level at the fan apex to about 230 feet at the Manawatu River at the Koputaroa confluence; the former shore-line along the foot of the hills, however, varied between these two points from about 500 feet to about 580 feet. Subsequent erosion and denudation reduced the sandstone formation to a relatively thin cover on the slopes of the fan.

Near its source the floodplain of the Koputaroa Stream lies directly on the denuded upper part of the Ohau fan, and lower down (for the remainder of its course to the Manawatu River) on the eroded and lowered surface of the Otaki sandstone. The floodplain deposit—clays and silts on a thinner basal layer of gravels—gradually gains thickness in a downstream direction, being from 10-12 feet east of Levin, up to 22 feet at Broadbelt's artesian (see map, Fig. 1), and 28 feet at Koputaroa railway-station. The floodplain varies in width from 15 chains to 30 chains.

The Ohau Series and the Otaki Series may be regarded as efficient and well-supplied aquifers although perched water tables on thin (sometimes extensive) lenses of clay, etc., undoubtedly occur in both. The upper, predominant layer of clayey silt of the Koputaroa floodplain, especially along its lower course, functions as an impervious, or relatively impervious cap, since the potential artesian water below is certainly under hydrostatic pressure. A peculiar feature is this effect of control by a comparatively narrow impervious strip. The expected natural rise of water under head to levels in the sandstone slopes (Fig. 4) on either side of the Koputaroa valley apparently does not occur sufficiently freely to relieve the hydrostatic pressure below the floodplain strip; hence hydrostatic conditions remain sufficient to give rise to the artesian-type springs of the locality.

The nature and origin of the conduits through which the springs discharge (Figs. 4 and 5) are problematical. There is no obvious arrangement or grouping of the springs to suggest fissures of linear extent. Each conduit seems to be of the nature of a single defined vertical perforation of the impervious silts, here about 25 feet in thickness. Layers, or lines, of porous material within the impervious silts lying parallel to the ground surface or to the bedding (if any) could reasonably be assumed. On the other hand, the occurrence of c pipes' of a porous material of slight and strictly limited lateral extent running at right angles to the deposit, or elongations of weakness of similar trend, to give rise to the formation of the spring conduits, presents a problem of some difficulty. The idea that the springs were initially formed in the early stages of floodplain deposition and persisted as it was gradually built

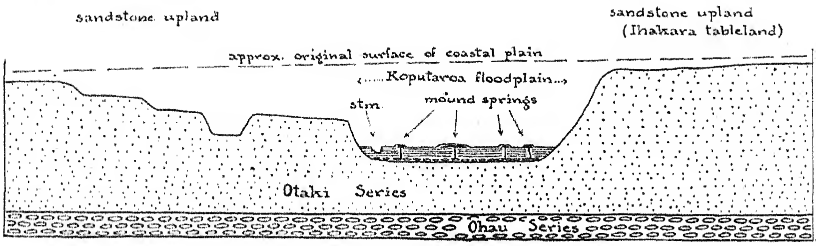


FIG. 4

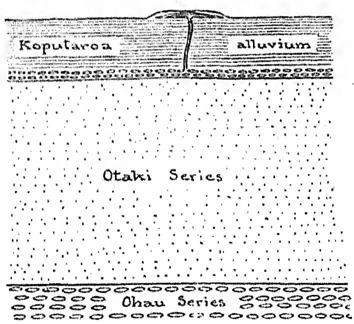


FIG. 5

up to its present level, while not inherently impossible, appears improbable. No satisfactory hypothesis of the origin of the spring conduits can at present be offered. Four ways in which apparently vertical mud-filled holes in alluvial ground could be formed were discussed by Marwick (1937) in his paper on the Upokongaro examples, but none of them appears to be applicable to the atresian-type spring conduits of the Horowhenua locality.

With an ever increasing need for adequate water supplies as pastoral and industrial enterprises develop, the presence in any other area of deep-seated, mound-forming springs such as those recorded in the present paper, should prove useful in indicating the occurrence there of perhaps otherwise unsuspected artesian waters.

REFERENCES

ADKIN, G. L. (1911): *Trans. N.Z. Inst.*, XLIII, 503.
MARWICK, J. (1937): *N.Z. J. Sci. and Tech.*, *XIX*, 333-6

THE MEASUREMENT OF NATURAL VENTILATION

By L. BASTINGS, Dominion Physical Laboratory, Department of Scientific and Industrial Research, Lower Hutt

(*Received for publication, 17th July, 1947*)

Summary

A technique has been developed for applying an aeroplane exhaust gas analyser to the measurement of natural ventilation rates in closed rooms. The method depends on the abnormal cooling of a heated wire in an atmosphere containing a small percentage of hydrogen and the change in resistance accompanying this cooling. Results are given of measurements made with this apparatus in domestic rooms under a variety of conditions.

THE rate of ventilation in a closed space is usually expressed in terms of the number of complete changes of air occurring per hour.

Thus a room of 1,000 cu. ft. is ventilated at the rate of two changes per hour when 2,000 cu. ft. per hour of fresh air finds its way or is forced into the room, while a like amount of room air is removed. It does not, of course, follow that in each half-hour the whole of the original air is replaced. Actually, if we assume complete mixing at all stages between residual and incoming air, 36.8 per cent. of the original air is still present within the room at the end of the half-hour. This follows from the following consideration. The rate of loss of the original air may be taken to be, at any time, proportional to the volume (V) of original air remaining at that time.

$$\text{i.e.} \quad \frac{dV}{dt} = -kV$$

where k is the rate of air change, assumed to be constant.
From this we have that

$$V_t = V_0 e^{-kt}$$

When one complete air change has occurred, $kt = 1$; so that

$$V_t = V_0 e^{-1} = 0.368,$$

or 36.8 per cent. of the original air is still included within the room.

Recommended rates of air change in rooms and buildings are given by various organizations. The Institute of Heating and Ventilating Engineers, London, (1) has issued a booklet in which it recommends rates of from ¾ up to 10 changes per hour in various specified types of rooms and buildings. From this booklet, the following typical examples are quoted.

Room or Building.	Air Changes per hour.	
	Not more than one external wall with doors or windows.	More than one external wall with doors or windows.
Flats and Residences		
Living Rooms	1	1½
Bedrooms	1½	2
Lavatories	2	2
Hotels		
Public Rooms	3	3
Dining Rooms	3	3
Sitting Rooms	1½	2
Schools		
Class Room	3	3
Laboratories	4	4
Assembly Halls	1	1½
Hospitals		
Wards	3	3
Operating Theatres	10	10
Offices	1½	2

In Great Britain, H.M. Inspector of Factories has recommended 6 changes per hour as the minimum which should be provided in factory workrooms generally, but there are a number of qualifications to this, covering special circumstances.

Similar standards are current for factories in New Zealand, also, but again a variety of circumstances may operate to modify these values over wide limits.

It has recently been shown (2) that, in modern dwellings in New Zealand, it is desirable to maintain a ventilation rate of at least three changes per hour, in order to counteract the tendency towards dampness and the consequent mould which is prevalent in New Zealand houses.

No method of measurement of rates of air ventilation is mentioned in any of these official or technical recommendations. When all the ventilation is provided by controlled inlets, such measurements are not very difficult. The velocity of the air at each inlet may be measured by anemometer or velometer, and the volume of air entering per minute calculated from this and from the cross sections of the inlet ports. However, when the whole or the major part of the ventilation is by natural circulation between the exterior and the interior, and the fresh air finds its way in through open windows and doors, or by the cracks and gaps around doors and windows, it is practically impossible to estimate the rate of air intake directly. If, however, a method can be discovered of estimating the proportion of the original air which remains in the room after a selected interval, this may be used to calculate the rate of air change.

The first attempt that appears to have been made to use this approach is recorded in the Report of the Building Research Board for 1927 (3). Measurements were made of the increase in the amount of carbon dioxide accumulating in the room in three hours, consequent upon the burning of three standard candles. An increase of 2.8 parts per 10,000 corresponded to 3 changes per hour in a room of 1,560 cu. ft., while an increase of 7.9 parts per 10,000 resulted from 1 change per hour. The method obviously suffers from being dependent critically on the conditions governing the burning of the candles, and does not in other ways lend itself very readily to general application.

Some time later, the Building Research Station investigated two further methods based upon the same general principle. In the first of these, following a suggestion of H. Hertz (4) in 1896, steam was applied to the air in a room at such a rate as to maintain a constant high relative humidity. The water supplying the steam was automatically replenished from a graduated vessel and the rate of replacement of water became a measure of the rate of air change in the room. The method proved unsatisfactory, however, because of the absorption of the water vapour by the walls and contents of the room.

The second method used by the Building Research Station is described briefly in the annual report of the Board for 1934 (5), and also in a paper by Marley (6). The method utilizes a small initial concentration of either hydrogen or carbon dioxide dispersed in the room and measures the rate of replacement of this gaseous mixture electrically. Two arms of a Wheatstone bridge circuit consist of two spirals of platinum wire, of approximately equal resistance. They are enclosed in adjacent cavities in a heavy copper block, and supplied with equal electric currents. In this way, they should normally attain almost identical temperature elevations. Two resistance coils, of similar magnitude to the platinum spirals, occupy the other two arms of the bridge. After balancing, one

spiral is exposed to normal air and the other to a continuously changing sample of the air from the room. Owing to the difference in thermal conductivity between normal air and air containing either hydrogen or carbon dioxide, the spirals are cooled differentially, and the bridge thrown out of balance. The deflection of the galvanometer inserted in the bridge thus becomes a measure of the deviation from balance and thence of the difference in conductivity between the two samples of air. If the deflection of the galvanometer is followed continuously for some time during the ventilation of the hydrogen-charged room, the rate of its return to the balanced position becomes a measure of the rate of replacement of the mixture by fresh air and thus of the rate of ventilation taking place.

This application of a Wheatstone net to the estimation of the composition of gas mixtures seems first to have been developed by Shakespeare and Daynes (7) under the title of the " katharometer ". A commercial instrument for estimating the concentration of carbon dioxide in flue gases has been put on the market by the Cambridge Instrument Company of England. Instruments of this type, described as " fuel mixture indicators " have been in use for some time in aeroplanes for estimating the percentage of carbon dioxide in the exhaust gases, with a view to adjusting the fuel-air ratio to greatest advantage.

One of the instruments, made available to this Laboratory by courtesy of the O.C. Repair and Maintenance Branch, R.N.Z.A.F., was investigated with a view to adaption to the measurement of ventilation rates. It consists of two units, the " analysis cell " and the " indicator unit ". The analysis cell contains four spirals of fine platinum wire, each mounted axially in a separate cylindrical cavity in a brass block, and connected electrically to form the four arms of a Wheatstone net. Two of these spirals are exposed to the atmosphere being sampled, and two to a sample of normal air, diffusing in through a fine hole in the brass block. In order to eliminate the effect of change in moisture content of the air, both samples are maintained in a state of saturation. The four elements are arranged in circuit with a ballistic tube current regulator and with the necessary resistances for sensitivity and zero adjustments. A battery of 12 volts supplies a current of about 252 milliamps. The out-of-balance current from the bridge is applied to an indicating galvanometer of the moving coil milliammeter type, the sensitivity and damping of which is controlled by series and shunt resistances. The scale of the meter is graduated to read the fuel-air ratio directly. The scale divisions are of uniform width and run about 12 to the inch. The pointer, though suitable for its original purpose, is too wide and blunt to allow of accurate subdivision of the scale ; therefore a finer linear scale was substituted for the one provided, and a short piece of fine wire attached to the pointer. In this way, it was possible to obtain a deflection of about 15 divisions for 1 per cent. of hydrogen, and to read the position of the pointer to tenths of a division. A reading lens (x 3) was used with advantage.

The process of measuring rates of air change in a room with this instrument is as follows. Hydrogen is released into the room from a storage bottle, to the extent of about 1 per cent. of the cubic content of the room (the danger level is about 9 per cent. of hydrogen). Meanwhile a fan mixes the air thoroughly. At the same time, a sample of fresh air is drawn through the analysis cell by an exhaust pump. The position of the galvanometer is now noted, and the hydrogen and fan shut off. The circuit is then switched to draw samples of the mixed

air continuously from the room. The departure of the galvanometer from its balanced position is watched closely, and the times of transit of the pointer over about 10 consecutive divisions of the scale are noted. From these observations, the time for one complete air change is calculated.

This calculation depends on the following considerations. Suppose d_1 and d_2 be the deflections at times t_1 and t_2. Then, assuming that the deflection at any time is proportional to the concentration of hydrogen at that time, we have :—

$$d_2 = d_1 e^{-(t_2 - t_1)k}$$

whence $(t_2 - t_1)k = \log_e d_1 - \log_e d_2$

or time for 1 change $= \dfrac{0.434\ (t_2 - t_1)}{\log d_1 - \log d_2}$

the logs now being to base 10.

The method is illustrated by the following example :—

Zero initially : 22.6

Div. No.	Transit Time. Min.	Sec.	Net Deflection.
40	43	10	17.5
39	44	5	16.5
38	45	5	15.5
37	46	20	14.5
36	47	45	13.5
35	49	15	12.5
34	50	45	11.5
33	52	20	10.5
32	53	55	9.5
31	56	10	8.5

Zero finally : 22.4 Mean Zero : 22.5

Range (d_1 to d_2).	Interval (t_2 - t_1). (minutes and seconds)	Difference ($\log d_1$ - $\log d_2$)	Time for 1 change. (minutes)
17.5 to 12.5	6 5	.1461	18.1
16.5 ,, 11.5	6 40	.1568	18.5
15.5 ,, 10.5	7 15	.1691	18.6
14.5 ,, 9.5	7 35	.1836	17.9
13.5 ,, 8.5	8 25	.2009	18.2
			Mean : 18.3

∴ Mean ventilation rate = 3.3 changes per hour.

RELIABILITY OF THE METHOD

With a view to testing the reliability of the method, a large box was lined with fibre-board to make it draught-tight, and was provided with a number of controlled inlets and outlets. Into this box was introduced a small proportion of hydrogen, and samples of the mixture were then run continuously through the analyser. The miniature room was next ventilated by withdrawing the mixture at a fixed rate by an exhaust pump, and measuring the volume extracted by passing it through a standard gas meter. The air replacing this mixture found its way in through an inlet provided for the purpose. Measurements of the rate of

ventilation, as estimated by the gas meter readings were found to agree with results deduced from the gas analyser method to within about 5 per cent. As ventilation rate is a quantity which probably varies appreciably from minute to minute in quite an irregular manner, it seems likely that this order of accuracy is sufficiently great for all ordinary purposes.

RESULTS OF THE MEASUREMENTS

Results of such measurements naturally vary between rather wide limits with changes in external conditions, and in relation to the aspect of the room with respect to the wind direction at the time of the measurement. However certain conclusions, which may serve as a general guide in reference to typical New Zealand houses of the modern type, have been arrived at. These conclusions are summarized in Table I.

TABLE I. RANGE OF VENTILATION RATES IN CLOSED ROOMS

	Number of air changes per hour.
Calm (Beaufort 0-1)	0.6 - 1.2
Breezy (,, 2-3)	1.3 - 2.4
Windy (,, 4-5)	2.4 - 3.0

INCREASE IN RATE DUE TO :

	Open Chimney.	Wide open Fanlight.	Wide open Window.	Brightly Burning Fire.
Calm	1.0 - 1.5	0.5 - 1.0	0.5 - 2.5	4 - 6
Breezy	1.5 - 2.0	1.0 - 2.0	3 - 7	

The results for open fanlight and open window are obviously particularly dependent on aspect with respect to the wind.

An interesting set of measurements was made in a room in which a special type of cornice ventilation had been installed. This type of ventilation has been discussed elsewhere (2). The original cornice in this room was removed, and the wallboard pierced so as to leave a gap of about ½ in. all round, at its junction with the four walls. This gap thus gave a free passage for air between the room and the attic space, between the ceiling and the hipped roof. A new cornice, 2 in. in width, was then installed, about 1 in. below the ceiling face, in order to direct any incoming air across the surface of the ceiling and so reduce the risk of direct down-draughts into the room. The results of measurements in this room are presented in Table II.

TABLE II. RANGE OF VENTILATION IN A ROOM WITH VENTILATED CORNICE

	Number of air changes per hour.
Calm (Beaufort 0-1)	1.8 - 2.5
Breezy (,, 2-3)	2.5 - 4.0
Windy (,, 4-5)	5 - 10

These results serve to indicate the difficulty of securing a ventilation rate in a room of three or more changes per hour at all times. If a room has an open fireplace or an efficient system of natural ventilation, such a rate of air change is not difficult to attain in breezy weather, but in calm weather, it is clearly necessary to supplement this by throwing open the windows as well. This point has a considerable bearing on the problem of combating the development of high humidities within a house in calm, damp weather and specially at night. At such times, conditions are most favourable for the first establishment of mould growth in the house.

APPLICATIONS

The instrument here described for measuring rates of ventilation is, in its present form, scarcely suitable for general industrial use. However, in the hands of an experienced technician, there appears to be no reason why it should not be applied to the measurement of ventilation rates in factories, offices and public buildings, if satisfactory conditions of measurement can be arranged.

ACKNOWLEDGMENT

My thanks are due to the Director, Dominion Physical Laboratory, for permission to publish this report.

REFERENCES

(1) "The Computation of Heat Requirements for Buildings." Institution of Heating and Ventilating Engineers, London, 1942.

(2) BASTINGS, L. (1947): *N.Z. J. Sci. and Tech.*, *28*, (*Sec. B*), 220.

(3) "Report of the Building Research Board for the year 1927," 102. H.M. Stationery Office, London.

(4) HERTZ, H. (1896): "Miscellaneous Papers," 20. London.

(5) "Report of the Building Research Board for the year 1934," 129. H.M. Stationery Office, London.

(6) MARLEY, W. G. (1935): *J. Inst. Heat. and Vent. Engrs.*, *2*, 499-503.

(7) SHAKESPEARE, G. A. and DAYNES, H. A. (1920): *Proc. Roy. Soc.*, *97*, 273.

THE NEW ZEALAND

JOURNAL OF SCIENCE

AND

TECHNOLOGY

Editor: D. Cairns, M.Sc. (Assistant Editor: M. O'Connor, M.Sc.) Department of Scientific and Industrial Research, Wellington

VOL. 29. SEC. B MAY, 1948 NUMBER 6

THE UPPER SENONIAN TRANSGRESSION IN NEW ZEALAND

By E. O. MACPHERSON, Geological Survey, Department of Scientific and Industrial Research

(*Received for publication, 16th July, 1947*)

Summary

The stratigraphy of Kekerangu district is briefly outlined and correlations with nearby Clarence Valley and North Canterbury are shown by columnar sections.

The truncation and overlap of Clarentian (Albian) by Piripauan (Upper Senonian) and younger units is indicated for Marlborough and North Canterbury.

Two subdued surfaces were planed in lower Mesozoic and older basement rock—a pre-Albian or pre-Upper Aptian, and a pre-Upper Senonian surface—and the time span separating these surfaces indicates that the pre-Upper Senonian surface must truncate the pre-Albian one.

This evidence is applied regionally to demonstrate a major unconformity in the Upper Cretaceous.

INTRODUCTION

DURING January, 1946, Cretaceous and Tertiary sediments at Kekerangu, East Marlborough, were mapped and subdivided into eight stratigraphic groups; samples were collected for micro-faunal analyses and Dr. H. J. Finlay assigned ages to several groups. An attempt was made to correlate these groups with those in the nearby Clarence Valley, south-west in North Canterbury and the east coast of the North Island. Although details of this stratigraphic work in Kekerangu Valley are yet to be published, it was thought that a preliminary discussion of the main points of evidence would stimulate awareness to the major unconformity between the Lower and Upper Cretaceous.

The relations of the Lower and Upper Cretaceous and Tertiary groups, and particularly the south-west overlap relations of these groups, will first be discussed from East Marlborough and North Canterbury, to illustrate the major break in this region, then an attempt will be made to show that this major unconformity and overlap relation applies in three other regions in New Zealand where Cretaceous sediments occur over considerable areas.

Stratigraphy of Kekerangu District

To illustrate the point taken, stratigraphic columns are introduced (see Fig. 1) and correlations with adjacent regions are indicated. Microfaunal age determinations are used for the time subdivisions at Kekerangu, but macrofaunal evidence, mainly in the form of ammonites, is used for regions beyond Kekerangu.

In Fig. 1 (Sect. 3) the subdivisions of the succession at Kekerangu are shown; the sediments are classified as follows:—

Rock Unit	Age	Approx. European Equivalent	Descriptive Note
Great Marlborough Conglomerate	Waitotaran	L. Pliocene	Coarse, angular, crudely bedded, conglomerate, 50-300 ft. thick. Disconformity and overlap.
Deadman Creek Group	Altonian	L. Miocene	Dark grey mudstone, silt, sandstone and thin conglomerate, 1,000 ft. Contact faulted. Unconformity and overlap. Ihungia of Poverty Bay and Hawke's Bay.
Kekerangu Group	Waitakian Duntroonian Whaingaroan	Mid. Oligocene L. Oligocene	Light grey, fine, marly limestone, marl and greensand, 500 ft. Contact faulted. Weber Limestone of Hawke's Bay. Amuri Limestone of Waipara.
Benmore Group	U. Bortonian	M. Eocene	Grey limy bentonitic shale, grey shaly and thin marly limestone. Basalt flow and dykes. 400 ft. Basal contact faulted. Wanstead of Hawke's Bay and Poverty Bay.
Amuri Limestone and Chert Member	Heretaungan	L. Eocene	White and drab, dense, fine grained siliceous limestone, 2,000 ft. Grey to black chert 600 ft. Disconformity.
Woolshed Shale	Piripauan	U. Senonian	Grey carbonaceous shale with large brown concretions, *Inoceramus* fragments, 2,800 ft. Resembles Lower Mangatu (of East Coast). Major unconformity.
Good Creek Group	Clarentian	Albian	Dark grey to black sand and shale banded, sheared and contorted, *Inoceramus*, 100 ft. cobble conglomerate at base, 3,000 ft. thick. Disconformity. Similar to the Tapuwaeroa of Hawke's Bay and Poverty Bay.
Whernside Group and Mangaotane Mudstone	Clarentian	Albian	Alternating grey sandstone and mudstone, 1,500 ft. thick. Similar to Raukumara of East Coast. Base not exposed.

The above groups and their relations have been mapped and discussed in detail elsewhere and the essential information required in the present discussion is included in the above table.

Southward Overlap

A study of the columnar sections shows that the Whernside and Good Creek groups thin to the south-west; they are almost absent in the Clarence-Deadman's Creek region (King, 1937, pp. 21-4) and twenty-five miles further south, at Kaikoura Peninsula are reduced to 500 feet or less. Still further south, at Amuri Bluff, the Clarentian (i.e. the Whernside and Good Creek groups) is absent and the Woolshed shale, i.e. Piripauan (Upper Senonian), rests on basement rock. A major hiatus is here indicated.

The age and correlation of the Woolshed Shale are shown on Fig. 1 (Sect. 3); the two pertinent microfauna samples from this group were assigned a "Top Cretaceous" age by Finlay and here a Piripauan age is accepted. It will be noted that this group evidently thins to the south-west; it is not recorded in the Clarence-Deadman Creek region (King, 1937, p. 22-4); the section in that region, however, is complicated by overthrusts. Thirty-five miles south-west the Piripauan is reduced to 800-1,000 feet and a thickness varying around that figure is characteristic of this group in North Canterbury. The exception is Malvern Hills; but in that district a tongue (or tongues) of terrestrial sediments (Glen Tunnel Coal Measures) increases the stratigraphic thickness.

These stratigraphic anomalies may have several explanations, but the evidence strongly favours major unconformity. It will be noted that two subdued surfaces cut in basement rock are involved; the older surface is pre-Clarentian, i.e. pre-Albian, and the younger, pre-Piripauan, i.e. pre-Upper Senonian, and the time-span separating them will not allow us to confuse them. Further the pre-Upper Senonian surface truncates the pre-Albian one, and Upper Senonian sediments transgress across the truncated edges of the Albian.

This view is not original; Hector (1873-74, p. 12) considered his Amuri Series (Lower Greensand) distinct from the overlying Waipara Formation (Cretaceo-Tertiary), and that master of the reconnaissance method, McKay (1890, pp. 146, 151, 152) records conclusive evidence for major unconformity between the Amuri Series and Waipara Formation in Clarence and Awatere valleys. I have discussed the evidence for a major break between the Good Creek Sand and Woolshed Shale elsewhere; the contact of these groups is obscurely exposed at the junction of Good Creek and Kekerangu Stream (additional regional evidence in support being shown on the columnar sections (Fig. 1)).

From this evidence it seems safe to conclude that the Clarentian terminated a sedimentary and diastrophic cycle, and the land was reduced to a terrain of low relief before the Piripauan was laid down.

The "Amuri Limestone" and Chert Member (Heretaungan, Lower Eocene) both thick and persistent in eastern Marlborough, also have the characteristic thinning and elimination to the south-west. The Chert Member is 500 feet thick in Benmore Stream, a branch of Kekerangu Stream, but to the south-west King (1937, p. 24) notes much thinning. At Kaikoura Peninsula the Chert Member at the base is missing, at least in sections examined by the writer, and an incomplete section of limestone with layers of clay (Waipawan, Paleocene) rests on the Piripauan, a two foot band of glauconitic sandstone marking the contact. The southward thinning of the 2,000 feet "Amuri Limestone" (Heretaungan, L. Eocene) is pronounced; the thickness of this group cannot be measured at Kaikoura Peninsula as the top is eroded.

It will be noted that this thinning and elimination of the " Amuri Limestone " and Chert Member and older groups, broadly coincides with the southern limit or margin of the pre-Upper Senonian sedimentary basin. This region of elimination of stratigraphic groups, separates the geosyncline from the shallow labile shelf region extending to the south and south-west. Such margins are usually belts of persistent instability and this may account for the thinning and elimination of stratigraphic units.

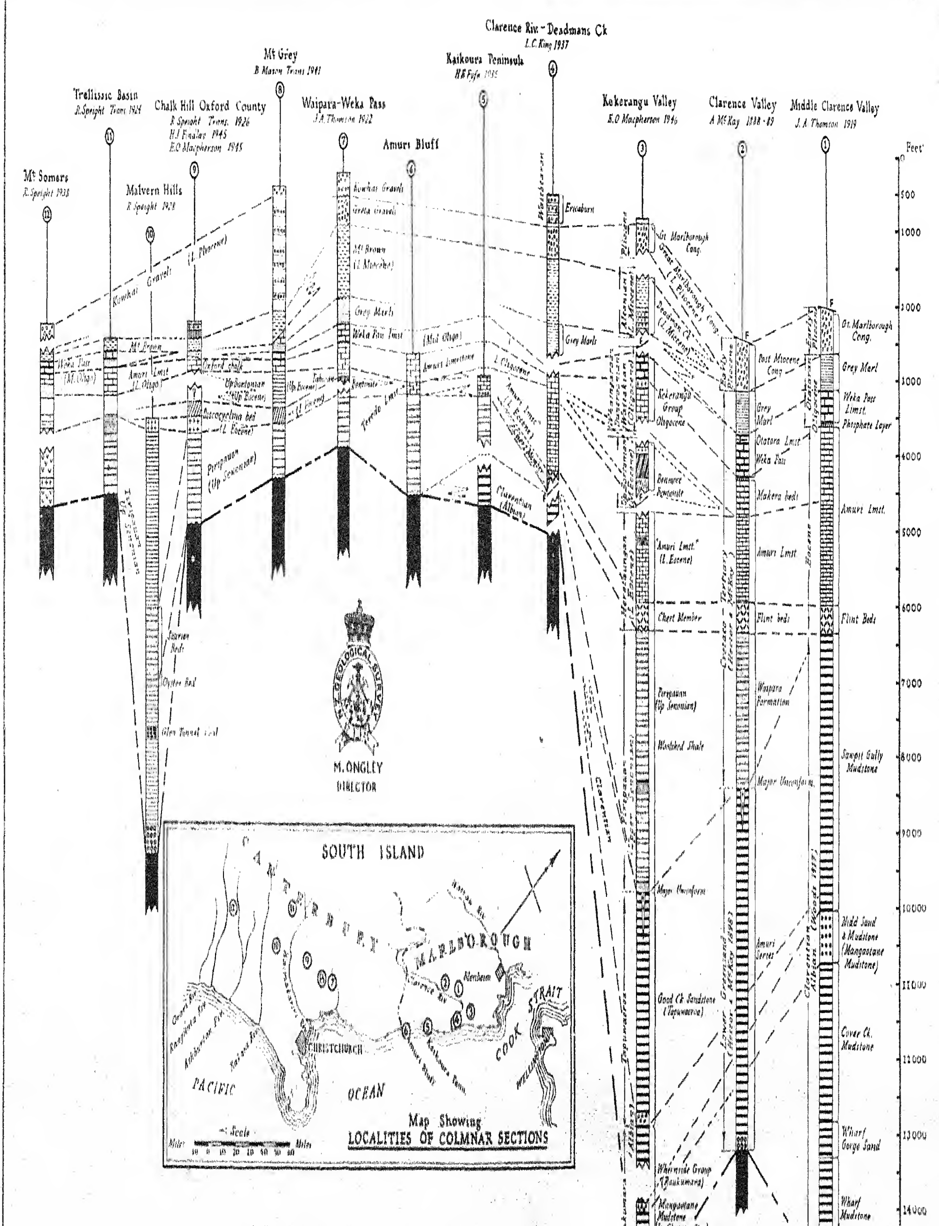
The siliceous " Amuri Limestone " and Chert Member were almost certainly deposited in the deeper regions of the Upper Senonian, expanding geosyncline, but not necessarily in deep water. The near correlatives of this group extend south-west across the labile shelf region, with greatly reduced thickness and marked change of facies, e.g. the bentonitic shale of Waipara-Weka Pass (Mangaorapan, Lower Eocene), Discocylina Beds (Speight, 1923) of Eyre River (Lower Eocene), and the Ashley Beds (Mason, 1941, pp. 110-1) of Mount Grey.

Disconformity, erosion and mild unconformity have been observed at the base of these groups (Lower Eocene) at several localities but the orogenic pulse, as elsewhere in this country, was not intense enough to be recorded as a regionally recognized stratigraphic break. Such a break is likely to be more pronounced on structural highs.

In 1946, Dr. B. H. Mason* recognized bentonite in the Waipara section and Finlay considered this bentonitic member Mangaorapan in age (Lower Eocene). Ongley and the writer later examined the Waipara bentonite, collected two samples for microfaunal analyses, and noted that the bentonite member was separated from the Waipara Greensand (?) by 50 feet to 100 feet of obscure section, and from the overlying limestone by a greater thickness of carbonaceous marl. The Waipara bentonite cannot therefore be correlated with the Kekerangu bentonite or the Wanstead bentonite of the East Coast by microfauna, the Waipara bentonite being Lower Eocene, the latter two, Middle Eocene. This bentonitic group will be observed at further localities in North Canterbury, but it may be missing on structural highs. The facies change to the south-west is much less obvious than in the underlying siliceous group.

I have discussed elsewhere why the name " Kekerangu Group " was anomalous when given to these sediments. That group is correlative in its lower parts with the Oxford chalk of Chalk Hill, and as a whole comprises Whaingaroan, Duntroonian and Waitakian time units, (Lower or Middle Oligocene). It is correlative with the Weka Pass limestone of the Waipara area, and the Weber of Hawke's Bay and Poverty Bay. Correlations with North Canterbury are shown on Fig. 1. During Whaingaroan-Waitakian times the sea spread south and south-west over the labile shelf region, and almost certainly the sediments of the youngest time unit, i.e. the Waitakian, overlapped sediments of older time units. Although extension and probably deepening of the geosyncline is indicated, these events were not progressive or continuous, but were interrupted by minor orogenic pulses, which are recorded by mild discordances and disconformities at the base of this group and also within it. These mild appearing breaks caused controversy among New Zealand

* Unpublished information supplied by Dr. B. H. Mason, Canterbury University College.



COLUMNAR SECTIONS

From Eastern Marlborough to North Canterbury

To Accompany a Report Entitled "The Upper Senonian Transgression in New Zealand" By E.O. Macpherson 1946

Fig.1

G.S. 677

G.M. 1947

stratigraphers, because angular discordance was expected, but regional angular discordances should not be expected during this phase of the orogenic cycle. The more obvious breaks should occur on the crestal parts and higher flanks of structural highs.

In Kekerangu area, owing to chaotic thrusting the basal contact of this group cannot be studied. Regional disconformity and unconformity show in several stratigraphic sections to the south-west (see Fig. 1). For example, at Amuri Bluff, by absence of units and thinning and truncation of units, at Chalk Hill where the Whaingaroan (Lower Oligocene) rest on the Eyre Sand (Lower Eocene), and at Waipara and Weka Pass, breaks between the Amuri limestone and Weka Pass stone, have been discussed by several observers.

Stratigraphic breaks higher in the succession were discussed elsewhere in connection with the Great Marlborough Conglomerate, and it was argued that these breaks became more pronounced in post-Waitakian times with the mounting intensity of recurrent orogenies. To the south-west the same arguments apparently hold; in that region the post-Weka Pass orogeny left a regionally recognized disconformity or unconformity in the succession.

Low dips and mild structural deformation are characteristic of this labile shelf region as in the concave region of the North Island segment.

Major Unconformity in Other Districts

The major unconformity between the Lower and Upper Cretaceous* has importance in the diastrophic and stratigraphic history of this country. In a recent account (1945, p. 18) I outlined its broader features, and argued that a late sedimentary and diastrophic cycle was initiated in the Upper Senonian; evidence from the present work, gives further support for this view and the present note may stimulate awareness of this unconformity. This view-point, as noted elsewhere, is not original for Marlborough and North Canterbury at least. McKay admits (1890, p. 146) that he did not at first accept Hector's view on this unconformity, but from his explorations in Clarence and Awatere valleys he states:—
" . . . the marine beds of the two formations are separated by a land surface during the continuance of which, in the Clarence and Awatere valleys, vast quantities of volcanic rocks were poured out and these as deposits of great thickness still separate the marine beds of the two formations."

(a) *North Auckland*.—Regionally, in this country, unconformity has been observed or implied, below the late Cretaceous (Upper Senonian) by several field geologists. J. M. Bell and L. de C. Clarke (1909, pp. 22, 47, 58) briefly described the contact of their Kaeo Series (Late Mesozoic) with the Waipapa Series (Pre-Cretaceous). They observed that there was an unconformity between these major groups, and that the basal Kaeo rested on the denuded surface of the Waipapa Series. Ferrar (1925, p. 38) records that Wood (MS.) assigned a Senonian age to fossils collected by McKay in Whangaroa Harbour (localities 106 and 107), i.e. from the Kaeo Series (see Fig. 2).

In the Whangarei region, to the south-east, Ferrar (1925, p. 34-5) discusses the contact of his Onerahi Series, which is in part late Cret-

* The standard Cretaceous section for this account is that discussed by Siemon Wm. Muller and Hubert G. Schenck; Bull. Am. Ass. Petrol. Geologists, March, 1943, *27*, No. 3.

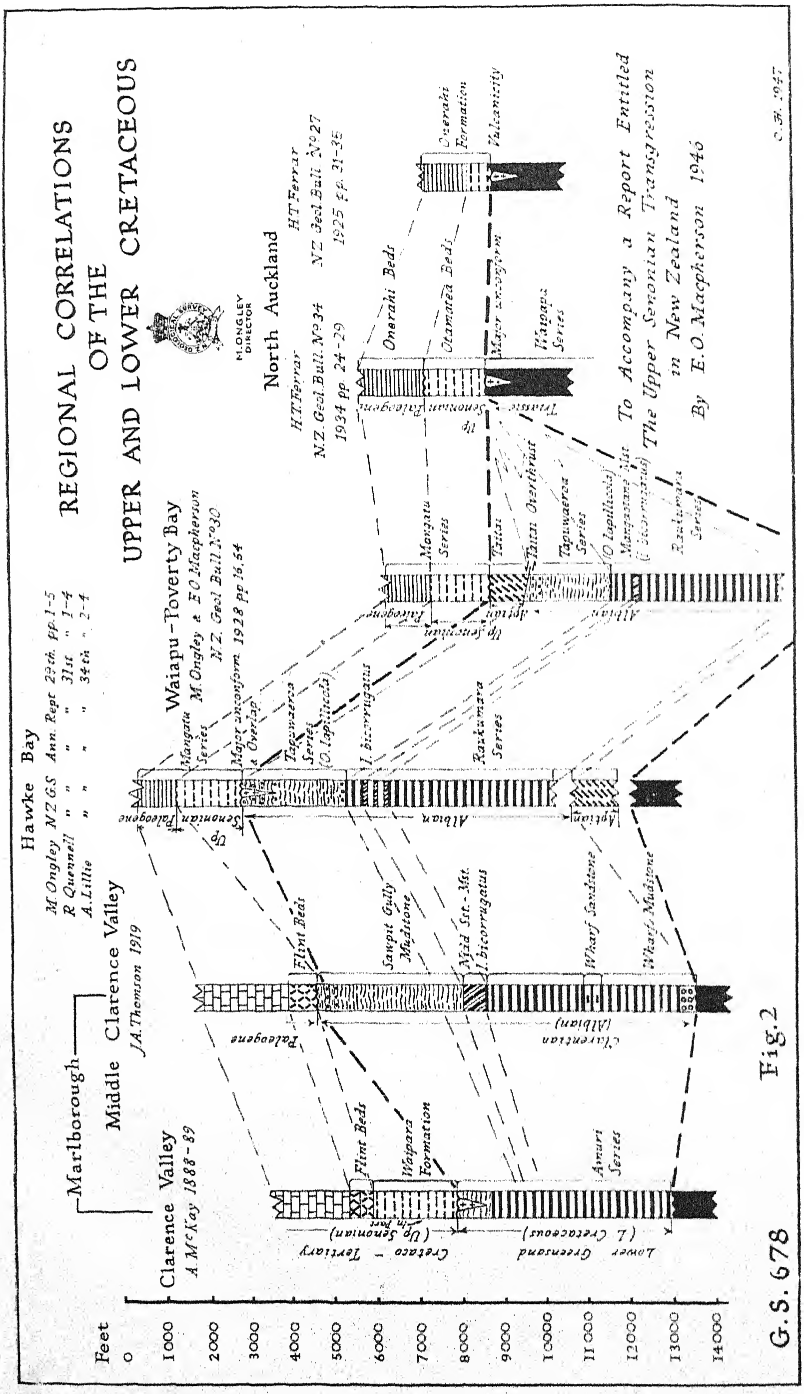

REGIONAL CORRELATIONS
OF THE
UPPER AND LOWER CRETACEOUS
M. ONGLEY
DIRECTOR
Marlborough
Clarence Valley
A. McKay 1888-89
Middle Clarence Valley
J.A. Thomson 1919
Hawke Bay
M. Ongley N.Z. G.S. Ann. Rept 29th pp. 1-5
R. Quennell " " " " 31st " 1-4
A. Lillie " " " " 34th " 2-4
Waiapu-Poverty Bay
M. Ongley & E.O. Macpherson
N.Z. Geol. Bull. No30
1928 pp 16, 54
North Auckland
H.T. Ferrar
N.Z. Geol. Bull. No34
1934 pp. 24-29
H.T. Ferrar
N.Z. Geol. Bull. No27
1925 pp. 31-35
To Accompany a Report Entitled
The Upper Senonian Transgression
in New Zealand
By E.O. Macpherson 1946
Feet
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
Flint Beds
Waipara Formation
Amuri Series
Cretaceo - Tertiary
(Up. Senonian in part)
Lower Greensand
(L. Cretaceous)
Sawpit Gully Mudstone
Middle Sst.-Mst.
I. Bicorrugatus
Wharf Sandstone
Wharf Mudstone
Paleogene
Clarentian
(Albian)
Mangatu Series
Major unconform. & Overlap
Tapuwaeroa Series
(O. lapillicola)
I. Bicorrugatus
Raukumara Series
Up. Senonian
Albian
Aptian
Taitai
Taitai Overthrust
Onerahi Beds
Otamatea Beds
Major unconform.
Waipapa Series
Triassic
Onerahi Formation
Vulcanicity
G.S. 678

Fig. 2

aceous, with the Waipapa Series and records that the Onerahi rests on the denuded surface of the basement group. Direct faunal evidence for age is here lacking, but from ammonite and other faunas collected in adjacent regions, an Upper Senonian age is accepted for the lower part of the Onerahi group.

In Dargaville-Rodney Subdivision, Ferrar (1934, p. 25) states that the basement Waipapa Series was base-levelled before being buried beneath the Upper Senonian, Otamatea group.

For North Auckland peninsula, it is well established that the Upper Senonian rests on the denuded surface of the Waipapa Series. However, the denuded surface in this region must not be timed or confused with the denuded surface buried below the Clarentian in Clarence and Awatere valleys and on the East Coast, which is pre-Albian; also there are present in the Kekerangu-Amuri Bluff region (as mentioned elsewhere) two denuded surfaces, one pre-Albian, the other pre-Upper Senonian. The North Auckland denuded surface noted by the field geologists referred to above, can be approximately timed with the pre-Upper Senonian denuded surface of Amuri Bluff, Marlborough and Canterbury.

Cretaceous sediments, older than Upper Senonian, have of late years been observed in the western part of North Auckland peninsula by several geologists, familiar with the Raukumara and Tapuwaeroa groups (Lower Cretaceous) of Waiapu and Hawke's Bay. To date, a diagnostic fauna has not been collected from these older Cretaceous groups, but *Ostrea lapillicola* Marwick (Ferrar, 1934, p. 28) was collected from the Paparoa Arm by McKay in 1888. This is a good index fossil, from the basal beds of the Tapuwaeroa group of Waiapu and Hawke's Bay and may be of late Albian age.

The evidence hence shows that Lower Cretaceous, probably Albian-Cenomanian, as well as Upper Senonian groups are present in North Auckland region, with the Upper Senonian overlapping onto the basement Waipapa Series. I have shown that this is the stratigraphic relation between these groups in North Canterbury; the marked transgressive habit of the Upper Senonian and Palaeogene over Lower Cretaceous onto older groups and the "togetherness" of each major Cretaceous group are characteristic of this major unconformity.

(b) *Waiapu-Poverty Bay.*—In the north-east region of the North Island, the Cretaceous sediment was subdivided into four groups (Ongley and Macpherson, 1928, pp. 16-32); in the uppermost member (Mangaotane Mudstone) of the very thick Raukumara Series, a small fauna was found with one (possibly two) significant fossils, *Inoceramus bicorrugatus* Marw. which also occurs in the Nidd sandstone and mudstone of the type locality, Clarence Valley, and below the thick Sawpit Gully mudstone (see Fig. 1).

Woods (1917, p. 2), mainly on an ammonite fauna, referred the Cover Creek mudstones, Nidd sandstones and mudstones, and the Sawpit Gully mudstones to the Lower Utatur of Southern India (Albian). It is noted here that the *Inoceramus bicorrugatus* of the Raukumara Series, which is in part correlative of the Nidd (see Fig. 2) has the 2,000 to 3,000 feet Tapuwaeroa group overlying it in Waiapu region, and the Nidd of the Clarence section is overlain by 3,200 feet of Sawpit Gully mudstones. It would, therefore, appear that the Tapuwaeroa group is also of Albian age.

A disconformity separates the Tapuwaeroa Series from the Raukumara, and in the grits and conglomerate at the base of the Tapuwaeroa some shark teeth and a small oyster were collected, but no diagnostic fauna. The oyster was the small *Ostrea lapillicola* Marwick, collected many years ago from the Paparoa Arm, North Auckland by McKay, and although a good index fossil, has only indirect value as to age. In a previous report on the Kekerangu area I have stressed the remarkable lithologic similarity of the Tapuwaeroa group to the Good Creek group of Kekerangu and the nearby Sawpit Gully mudstones. This correlation is shown on the accompanying columnar sections.

The Taitai Series (Aptian) occurs in thrust relation with the Tapuwaeroa, as isolated nappe remnants over approximately 1,000 sq. miles in Waiapu and western Poverty Bay (Ongley and Macpherson, 1928, pp. 28, 54). This structural relation seems clear in the field and does not depend solely on the age of the Taitai, but Ongley (1929, pp. 8-9) found two forms in the Taitai of western Poverty Bay, *Maccoyella magnata* n.sp. and *Aucellina* sp. (Marwick, 1929) which indicated an Upper Aptian age and hence gave support to the regional structural evidence for the Taitai Overthrust (Ongley, 1930). In Waiapu and Poverty Bay, we thus have evidence of two Lower Cretaceous stages, Albian and Upper Aptian, with indirect evidence that the age of the Tapuwaeroa Series is almost certainly Albian or possibly Cenomanian.

Henderson and Ongley (1919, p. 34) classified about 5,000 feet of claystones, carbonaceous shales, light grey cherty limestone and chert and light grey argillaceous limestone of the Poverty Bay region under the name Mangatu Series. This was a natural series for it grouped a succession of related lithologic types. These field geologists stressed that only the lower portion may be Cretaceous, and the upper, strongly calcareous part, on lithology was correlated with the Amuri limestone of Marlborough and North Canterbury. We now know, that the Mangatu Series, embraces Upper Senonian and Palaeogene groups separated by several mild disconformities.

The Mangatu Series overlies the Tapuwaeroa, over many square miles in western Poverty Bay and Waiapu County, and the colour contrast between the black, drossy, chaotically folded Tapuwaeroa and the lighter coloured Mangatu sediments is striking. At rare places along their folded, faulted and kneaded surface of contact, relatively small isolated masses of Taitai are exposed as the Mangatu is eroded back, and similar masses stand up prominently as isolated knobs and hills on the chaotically deformed Tapuwaeroa autochthon. These Taitai nappe remnants show that the Taitai thrust-sheet was eroded into isolated remnants before the Mangatu sediments were deposited, and the little development or absence of coarse clastics, and prevalence of grey and light-grey fine-grained sediments, carbonaceous shales and limestone containing chemically precipitated glauconite, silica, and lime carbonate show that the pre-Mangatu land had been reduced to subdued relief before Mangatu times.

A few ammonites were collected from the Mangatu Series at Port Awanui by McKay and an ammonite cast in the Whatatutu district by Ongley. Marshall (1926, pp. 132, 148, 192) refers two of the Port Awanui ammonites to forms from the Bulls Point and Batley localities, i.e. the Otamatea Series (Upper Senonian).

Since Marshall published his account, two more ammonites were

collected from the Awanui beach and two from the head of Home Creek, Mangatu S.D. A. Olsson compared these forms with Marshall's illustrations and descriptions and considered them close to *Vertebrites murdochi* Marsh., so additional collecting tends to confirm the Upper Senonian age of the Lower Mangatu Series.

Apparently in this region we have the same sequence and hiatus as in Marlborough, North Canterbury, and North Auckland, i.e. Upper Senonian and Palaeogene overlying Albian, with the lower portion (Cenomanian, Turonian, Santonian) of the Upper Cretaceous missing. In the Poverty Bay-Waiapu region we have the structural complication of Taitai (Upper Aptian) in thrust relation with the Tapuwaeroa; this, however, emphasizes the evidence of major unconformity. In Waiapu and Poverty Bay regions, the Upper Senonian and Palaeogene, as in the other regions discussed, have the persistent habit of overlap on to Lower Cretaceous groups and probably older Mesozoic rocks.

(c) *Central and Southern Hawke's Bay*.—Central and southern Hawke's Bay is the remaining region where lower and upper marine Cretaceous are extensively developed. These sediments were studied during 1926-40 by field geologists of the New Zealand Geological Survey and several oil companies. Unfortunately their work is scattered through unpublished reports, notes and field maps and is not readily accessible. The Lower Cretaceous section here may have a maximum thickness of 8,000 feet, the Upper Cretaceous 4,000 feet.

C. W. Washburne and the writer spent almost a year on reconnaissance in this region in 1926-27. The Raukumara, Tapuwaeroa, and Mangatu Series (restricted) were recognized and several anticlines in the Waipukurau-Waipawa district and eastward to the coast, also southward to Titree were studied in some detail. The broad stratigraphic feature emerged, that Raukumara and Tapuwaeroa groups were present below the Waipawa Series (Upper Senonian), in the axial parts of folds, only on structures in the eastern part of the region, whereas on anticlines along the western part of the region the Waipawa Series rested on the basement rock. The transgressive habit of the Upper Senonian was here again reasonably well established.

Ongley and associates studied the Lower and Upper Cretaceous of Eketahuna Subdivision and central Hawke's Bay during 1930-40 (*N.Z. Geol. Surv.*, 25th-35th Ann. Rept.) This work firmly established the Cretaceous groups regionally, for Ongley found *Inoceramus bicorrugatus* Marw. in the Mangaotane Mudstone in the upper part of the Raukumara Series and *Ostrea lapillicola* in the basal Tapuwaeroa. Later Quennell and Brown, and Lillie, extended the occurrence of these fossils into the Whangai Range and Elsthorpe anticlines in Motuotaraia and Pourerere Survey Districts.

The Taitai group was also recognized in the Eketahuna district. Here *Aucellina* was collected, but *Maccoyella*, that occurred with it in the Taitai of western Poverty Bay, was not found and it was not established whether the Taitai of this region was in thrust contact with the Tapuwaeroa; it may be that here the Raukumara and Tapuwaeroa are in depositional contact with this Upper Aptian group.

The Waipawa Series (McKay, 1877), which is in the main the same group as the Mangatu and Woolshed Shale, overlies the Lower Cretaceous. The several formations and members of this group are lithologically similar to those found further to the north-east, viz. light and

dark-grey shales, carbonaceous shales, cherty shales and limestones, and light-grey argillaceous limestones. Here again we have an obvious lithologic unity of late Cretaceous and also Palaeogene groups.

Representative ammonite or gastropod faunas, such as occur in the Piripauan of North Canterbury, have not been collected from the Waipawa Series and the Upper Senonian age depends on four or five ammonites collected from the Waipawa Series in central and southern Hawke's Bay, some of which were identified by Dr. F. Spath of the British Museum (Marwick, 1935, p. 11). Other ammonites, collected by oil companies, may have been kept for private collections, but have not been identified. These few forms, in conjunction with the strong similarity both in appearance, condition of deposition and position in the Cretaceous succession with other regions described, make a strong case for Upper Senonian age.

Microfaunas could also be used to support the late Cretaceous age of part of the Waipawa Series, but for the purposes of this discussion, it is of particular interest to establish the age of the Lower and Upper Cretaceous groups on ammonites, and to a lesser extent on other macro-fossils (Woods, 1917, Wilckens, 1922).

Ongley published a geological map of the southern part of this region (*N.Z Geol. Surv.*, 29th Ann. Rept., p. 4) which shows the characteristic transgression of the late Cretaceous and Palaeogene on to Lower Cretaceous and probably Jurassic basement.

The over-all stratigraphic picture in this region is, therefore, parallel to the other three regions discussed, i.e. there are present Upper Senonian sediments overlying late Albian or possibly lower Cenomanian, with the lower stages of the Upper Cretaceous missing, and the Upper Senonian and Palaeogene on-lapping Lower Cretaceous and probably older Mesozoic groups.

Throughout this discussion contacts have not been described to demonstrate this major unconformity, for it is recognized that such breaks are not well shown in the usual slumped cross-section, and major unconformities are best realized in broad regional plan. When the sea floods a reduced terrain, as in this problem, conspicuous basal conglomerates are only rarely developed, and almost all the sediment in the basal formation of the younger group is soft residual from the old terrain. This gives transition and blended or welded contacts, and when the two groups and their unconformable surface of contact are later chaotically folded, faulted and kneaded together as in this case, the chance of observing ideal text-book unconformity is not bright. However, such unconformable contacts are found where outcrop conditions are favourable.

Age of Major Unconformity

The bare essential stratigraphic and faunal evidence for this unconformity has been discussed for four regions; with some additional details for Kekerangu and adjoining districts. The exact timing still has problems, which are, however, mainly concerned with age adjustments and will not greatly alter the main thesis.

Several writers have paraphrased or partly quoted Woods (1917) when discussing the age of these Cretaceous sediments, but it is preferable that he should be quoted in full. When commenting on the age of the Clarentian, Wood (p. 4) remarks: "The beds of Lower Utatur age in New Zealand rest on deposits of much earlier date, showing that the

widespread "Cenomanian overlap" extended to this remote region and further. The deposition of sediments of Lower Utatur age in New Zealand was apparently followed by an uplift, since the middle Utatur beds with *Acanthoceras* (Lower Chalk), which occurs in Pondichery, Madagascar, Zululand and Japan, are not known to be represented." The identification of *Acanthoceras ultimum* Marsh. in the Bulls Point ammonite fauna (Marshall, 1926, p. 202) may neceessitate some modification of this statement, but this is merely a detail and is involved with the apparent mixing of the Kaipara ammonite faunas.

When summarizing his views based on his study of the Lower and Upper Cretaceous ammonite faunas and other macrofossils of the South Island Wood states: "From the foregoing account it will be seen that in this region (Amuri to Malvern Hills) the only Cretaceous horizon which can be recognized at present is the Upper Senonian. There is no evidence for the existence of Cenomanian (Lower Chalk) Turonian or Lower Senonian; so that here we have an instance of the Senonian transgression similar to that which occurs in Pondichery, Madagascar, South Africa and Quiriquina (Chile)."

The above quotation aptly states the main contention of the present account, but the problem has here been approached mainly from regional stratigraphic and structural evidence.

Wilckens (1922) studied the gastropods from the late Cretaceous sediments of the South Island and Marshall (1926) published his work on the ammonite fauna from this group mainly from the North Auckland peninsula. Both palaeontologists assigned an Upper Senonian age. Marshall indicates the Upper Santonian or Lower Campanian substages as the probable European equivalent, but his studies revealed some disturbing anomalies.

Marshall discovered ammonites at Bulls Point, and Batley, Kaipara Harbour, in 1917, chiefly in loose concretions on beaches, and undertook the specialized work of describing them; he took his material to England and checked it with type material. His studies revealed an apparently mixed fauna, for with the Upper Senonian forms he recognized several ammonites that could quite definitely be referred to the Cenomanian, *Acanthoceras ultimum* Marsh. a zone genus of the Upper Cenomanian being particularly disturbing. Marshall records (1926, p. 202) that if the anomalous forms found in the Kaipara fauna had been alone, the sediments would have to be referred to the Cenomanian.

The value of his study is reduced because a detailed map showing stratigraphy and structure is not available and unfortunately the specimens were not collected in place. Marshall, who considered (p. 203) the fauna Upper Senonian but not a normal one, discounts mixing of faunas, because at all three collecting grounds a fairly constant proportion of Cenomanian forms was present with Upper Senonian. This result should be accepted, but maybe with some reservations. Indeed, the Upper Senonian age seems quite definitely established, but the question of derived Cenomanian forms with the Upper Senonian fauna, should be reconsidered for the following reasons. The Bulls Point and Batley ammonite localities occur on a structurally involved "high" of Otamatea beds, with Palaeogene and lower Neogene overlapping around the flanks. An unconformable contact with Raukumara and Tapuwaeroa groups must be strongly suspected either below the crest of this high, or a short distance down the flanks, particularly the western flank. The

transgressing Senonian sea could erode Albian or Cenomanian ammonites from older Cretaceous sediments and incorporate them in the Upper Cretaceous sediments. This would particularly apply to hard siliceous concretions, which are resistant enough to survive through several sedimentary cycles.

Point is given to this argument, for in Paparoa River (Paparoa Arm) about three miles west from Batley, and four miles from Bulls Point, McKay (see Ferrar, 1924, p. 28) collected a fossil that Marwick identified as *Ostrea lapillicola* Marw., and as noted elsewhere this is a good index fossil from the basal Tapuwaeroa group. Either this group is present on the Kaipara structural high, or *Ostrea lapillicola* is derived and was collected from Otamatea beds; the Cenomanian ammonites could have been derived from this possible common source.

The presence of Upper Senonian and Upper Cenomanian zone ammonites compounded into one Upper Senonian substage is difficult to accept, but stranger things have happened; however, before finally accepting Marshall's explanation, the Kaipara ammonites should be collected in place.

CONCLUSION

Two subdued surfaces were cut on the basement rock (Jurassic and older), the first being pre-Aptian or pre-Albian, the second pre-Upper Senonian, and from their relations in time and space the younger surface must truncate the older. The so-called post-Hokonui orogeny predates the older surface and as Neocomian sediments are not, as far as we know, present in this country, this surface is post-Tithonian (Cotton, 1916). The oldest Lower Cretaceous sediments reasonably well established are Upper Aptian, and therefore the age of the so-called post-Hokonui orogeny must be post-Tithonian and pre-Aptian, i.e. Late Cimmerian (Stille's List, 1924).

The world-wide "Cenomanian" transgression commenced in Europe in the Aptian or Albian and lasted into the Cenomanian; this timing agrees reasonably well with New Zealand, although there is no direct faunal evidence that Cenomanian* sediments occur here. In the late Albian or early Cenomanian in New Zealand, sedimentation was interrupted by orogenesis, which culminated in overthrusting in the north-east region of the North Island, vulcanicity in Clarence and Awatere valleys, and possibly also in the Brocken Range, East Wellington (Brown, 1943); in North Auckland Peninsula, this is a post-Clarentian or Tapuwaeroa orogeny, Austrian sub-Hercynian Orogenic Epoch (Stille's List, 1924).

Cretaceous marine sediments were not deposited in this country from late Albian or possibly Upper Cenomanian until the Upper Senonian, when geosynclinal evolution was resumed, and the Upper Senonian sea transgressed over a subdued terrain cut on Lower Cretaceous marine and terrestrial sediments, and basement rock.

The almost world-wide Senonian transgression did not reach the New Zealand region until the Upper Senonian; there was no Laramide movement in this country, or at least it was not sufficiently intense to be

* Marshall (1926) has identified *Acanthoceras ultimum* Marsh. from North Auckland which he considers close to *A. rotomagense* (Upper Cenomanian). This possibly indicates sea retreat in the Cenomanian, for this Upper Cenomanian zone ammonite is absent from the Clarentian of the type locality (see Wood, 1917, p. 4).

recorded as a readily observed regional unconformity, or to break down the sedimentary environment of late Cretaceous times. This particular sedimentary environment continued almost to the end of the Palaeogene (post-Waitakian, Middle Oligocene).

REFERENCES

BELL, J. M., and CLARKE, E. de C. (1909): Whangaroa Subdivision, Hokianga Division, *N.Z. Geol. Surv., Bull. 8.*

BROWN, D. A. (1943): The Geology of the Brocken Range and Kaiwhata Valley, East Wellington. *Trans. Roy. Soc. N.Z., 72,* 347-51.

COTTON, C. A. (1916): Structure and Later Geological History of New Zealand. *Geol. Mag., 3,* 243.

FERRAR, H. T. (1925): The Geology of the Whangarei—Bay of Islands Subdivision, Kaipara Division. *N.Z. Geol. Surv. Bull 27.*

—— (1934): Geology of the Dargaville-Rodney Subdivision. *N.Z. Geol. Surv. Bull. 30.*

HECTOR, J. (1874): *Rept. Geol. Explor.,* 1873-74.

HENDERSON, J., and ONGLEY, M. (1919): The Geology of Gisborne and Whatatutu Subdivisions. *N.Z. Geol. Surv. Bull. 21.*

KING, L. C. (1937): The Tertiary Sequence in North Eastern Marlborough. *Trans. Roy. Soc. N.Z., 67*

MACPHERSON, E. O. (1946): An Outline of Late Cretaceous and Tertiary Diastrophism in New Zealand. *N.Z. Geol Surv.; Geol. Memoir 6.*

MARWICK, J. (1935): *N.Z. Geol. Surv. 29th Ann. Rept.*

—— (1939): Maccoyella and Aucellina in the Taitai Series: *Trans. Roy. Soc. N.Z., 68.*

MARSHALL, P. (1926): The Upper Cretaceous Ammonites of New Zealand. *Trans. and Proc. N.Z. Inst., 56,* 129-210.

MASON, B. (1941): The Geology of Mount Grey District, North Canterbury. *Trans. Roy. Soc. N.Z., 71.*

MCKAY, A. (1877): Report on the County between Masterton and Napier. *Rept. Geol. Explor.,* 1876-77.

—— (1890): On the Geology of Marlborough and the Amuri District of Nelson. *Rept. Geol. Explor.* during 1888-89, 85-185.

ONGLEY, M. (1929): *N.Z. Geol. Surv. 24th Ann. Rept.*

—— (1930): The Taitai Overthrust, Raukumara Peninsula. *N.Z. J. Sci. and Tech., 11,* 376-82.

——— 1935): *N.Z. Geol. Surv. 29th Ann. Rept.*

—— (1936): *N.Z. Geol. Surv. 30th Ann. Rept.*

ONGLEY and MACPHERSON (1928): The Geology of Waiapu Subdivision. *N.Z. Geol. Surv. Bull. 30.*

SPEIGHT, R. (1928): The Geology of View Hills and Neighbourhood. *Trans. N.Z. Inst., 58,* 408-31.

STILLE, H. (1924): *Grundfr. der vergleich. Tekton.,* Berlin.

WILCKENS, OTTO. (1922): The Upper Cretaceous Gastropods of New Zealand. *N.Z. Geol. Surv. Pal. Bull. 9.*

WOODS, H. (1917): The Cretaceous Faunas of the North Eastern Part of the South Island of New Zealand. *N.Z. Geol. Surv. Pal. Bull. 4.*

ADDENDUM

NOTES ON MICROFAUNAL EVIDENCE AND CORRELATIONS MADE IN THIS PAPER

By H. J. FINLAY, Micropalæontologist, N.Z. Geological Survey

(*Received for publication, 27th July, 1948*)

THE present paper has been held up in the press, and internal evidence suggests that parts of it were written at different times, and were unable to be co-ordinated because of Mr. Macpherson's untimely death. Mr. Macpherson's earliest viewpoint on two matters was that commonly held by geologists at the time but such a viewpoint has since been revised in the light of recent microfaunal evidence. It has seemed best to leave Mr. Macpherson's manuscript as little altered as possible, and to mention the discrepancies in this note. The matters most in conflict concern the age and correlation of (a) the Tapuwaeroa Series, (b) the Amuri Limestone.

THE TAPUWAEROA SERIES

The Tapuwaeroa beds of the North Island were evidently believed by Mr. Macpherson to be lithologically very similar to his Good Creek Group (see pp. 281 and 287). In a more detailed paper on the Kekerangu Valley, he also stresses their lithological similarity to the Sawpit Gully mudstones, the highest unit of Thomson's type Clarentian. Because of this, and the occurrence of *Inoceramus bicorrugatus* in both the Mangaotane mudstone (underlying Tapuwaeroa beds) and the Nidd sandstones and mudstones (underlying Sawpit Gully) he makes a definite age correlation of Tapuwaeroa with Good Creek and Sawpit Gully, and places it in the Clarentian, with a major unconformity above; but evidence other than lithological for this presumed correlation is not good. The only index macrofossil of the type Tapuwaeroa (*Ostrea lapillicola*) has not been found in the Good Creek or Sawpit Gully beds, nor has *Inoceramus porrectus* of Sawpit Gully been found in Tapuwaeroa beds.

The type Clarentian section has been carefully sampled for microfaunas by Dr. Mason; no fauna was obtained from the three lowest members (Basal Conglomerate, Wharf Mudstones, Wharf Gorge Sandstones), but the three upper members (Cover Creek Mudstones, Nidd Sandstones and Mudstones, Sawpit Gully Mudstones) yielded faunas to within a few feet of the overlying Flint Beds. These microfaunas are so similar to each other, and to that from the Mangaotane Mudstone, and so essentially different from any others in New Zealand, that one must conclude at present that the Clarentian is microfaunally a distinct unit, and that there is as much evidence for correlating the Mangaotane with the top member as with any other. I have already pointed out (Finlay, 1940) that this characteristic Clarentian microfauna bears little relation to succeeding New Zealand faunas, but is rather like that of the Upper Albian Grayson Formation of Texas.

The Mangaotane mudstone is, by definition, the top member of the Raukumara Series (Ongley and Macpherson, 1928) of Poverty Bay (the lower members have not yielded microfaunas), but the petroleum geologists who have worked in this area have given it a separate formation name, the Puketoro, separated from the rest of the Raukumara by

a marked angular unconformity, and from the overlying Rakauroa formation by a disconformity. In the terminology of the geologists of the Survey, the name Tapuwaeroa (Ongley and Macpherson, 1928) was given to beds mapped as overlying the Raukumara and underlying the Mangatu, unconformably in each case; and the name Whangai (Quennell, 1937) to still higher beds which evidently represent the Rakauroa in both lithology and microfauna. It should be emphasised that there is a greater field break between the Raukumara (Puketoro part) and the Tapuwaeroa than between the Tapuwaeroa and Whangai. The microfunas support this. The Rakauroa and Whangai have yielded abundant species, both arenaceous and calcareous, which plainly show their approximate equivalence and also their correlation with the Piripauan of the Mid-Waipara (*Gaudryina healyi, Dorothia elongata, Gyroidina globosa,* etc.); overlying each of them, with little or no break, is the still younger Cretaceous Teurian, in which *Rzehakina* has its last occurrence in New Zealand. The type Tapuwaeroa has not yet been sampled, and no microfaunas have been obtained from other beds containing *Ostrea lapillicola,* but the type Puketoro and Rakauroa, and the Whangai and underlying beds have more than once been collected throughout.

The outstanding faunal feature of the Puketoro, the *bicorrugatus* mudstones elsewhere, and the type Clarentian (right up to the top Sawpit Gully Beds) is the absence of *Rzehakina* and the abundance of *Globigerina cretacea.* (Previous reports of rare occurrences of *Rzehakina* in the Puketoro are based on introduced specimens.) In the Puketoro of Tangaruhe Stream, *Spiroplectinata* cf. *annectens* (P. & J.) is common in one sample—an English Lower Cretaceous species, differing considerably from the Upper Turonian *S. jaekeli* Franke, as Brotzen (1944) has pointed out. Near the top of the Puketoro in Puketoro Stream, *Gaudryinella* cf. *delrioensis* Plummer, another Lower Cretaceous form from Texas is common. At the very top of the Puketoro occur "red beds," with only arenaceous and siliceous species; although the generic association is very similar to that in the succeeding Rakauroa, there is no sign of *Rzehakina,* which is abundant immediately the Rakauroa is entered.

The absence of *Globigerina cretacea* from the lower Rakauroa, lower Piripauan, and infra-Whangai might be ascribed to facies since no calcareous species occur, but it is significant that as calcareous species appear and become abundant in the upper parts of these beds there is no return of *cretacea. Rzehakina* remains common throughout the Rakauroa and Whangai, and up to the top of the succeeding Teurian. The Puketoro also frequently carries (up to the top "red beds") an *Ammobaculites* n.sp. of coarse and roughish texture, while the Rakauroa just as frequently carries a related but larger and smoother species. Many samples in Puketoro, Tangaruhe and Te Uri Streams, and elsewhere in the Rakauroa contain *Gaudryina healyi, Dorothia elongata, Palmula rakauroana, Bulimina rakauroana, Gyroidina globosa,* etc., which are characteristic species of the type Piripauan. The succeeding Teurian beds in every case carry *Gaudryina whangaia, Frondicularia teuria, Planularia whangaia, Palmula thalmanni,* etc., which are characteristic upper Cretaceous forms not found in the Piripauan. At Tangaruhe and Te Uri Streams the base of the Teurian is a thick bed of

glauconite, but at Puketoro Stream the contact is within argillitic siliceous shale with no marked break.

Thus it would appear that the Raukumara (plus Puketoro) and Clarentian are in the Lower Cretaceous (*annectens, delrioensis, cretacea*, etc.), while the Rakauroa and Teurian are closely related members of the Upper Cretaceous (*Rzehakina* elsewhere has a range of Upper Senonian to Paleocene). In several places the lower Rakauroa beds have been called Tapuwaeroa by various geologists, though they have not the black "drossy shale" appearance of those in the Tapuwaeroa Valley. If this correlation is correct, there is no faunal evidence to separate them in age from the more splintery and argillitic Whangai up into which they pass, while there is good evidence to correlate them both with the Piripauan. If it is not correct, then the real Tapuwaeroa is something that comes between Clarentian and Piripauan, and no fauna is yet known from it except *O. lapillicola*. It should therefore be stressed that Mr. Macpherson's correlation of his Good Creek Group and the Sawpit Gully mudstones with the Tapuwaeroa is lithological entirely. Unless *I. bicorrugatus* does prove to be limited to the Mangaotane mudstone and the Nidd member of the Clarentian, and unless the, as yet faunally unknown, Tapuwaeroa proves to contain species like the Sawpit Gully member, then there is a likelihood that Good Creek and similar beds overlying definite Clarentian may be Piripauan. It is significant that the Vacuum Oil geologists mapped the black shales that occur above the basal Tapuwaeroa conglomerates in Tapuwaeroa Valley as being in the lower part of their Rakauroa, and that any microfaunas obtained from them or associated beds have been of the *Rzehakina-Gaudryina healyi* Piripauan assemblage. The subject is an involved one, but the above explanation may help to clarify it.

THE AMURI LIMESTONE

The Amuri Limestone has been the subject of a misconception by Mr. Macpherson throughout the paper. At the type locality (Amuri Bluff), a sample from the base of the limestone (Dr. Mason) yielded a Mangaorapan fauna, while one from the middle and one from the top gave Upper Bortonian faunas. Thus the type Amuri stone ranges from Lower to Middle Eocene, and there is no Lower Oligocene there at all. It is overlain by supposed "Weka Pass Stone," which at Amuri Bluff has yielded only Waitakian microfaunas, the Duntroonian being apparently absent. Limestone which has been called "Amuri" elsewhere such as in the Trelissic Basin) does contain Whaingaroan faunas, and the Eocene is unrepresented in it; thus two different beds are concerned.

Due to this misconception Mr. Macpherson has made some erroneous correlations in his paper and in his columnar sections shown in Fig. 1. In the first five columns at the left, his "Amuri limestone" is the Oligocene one (which may be referred to as "Amuri B"), and there is a very thin remnant of this in the next column (East branch of Grey River only). Below this in the Grey district, the Keretu sandstone (Upper Bortonian) and Ashley mudstone (Mangaorapan) represent the real Amuri limestone, confined at the type locality to these two ages. In the Waipara-Weka Pass column, the actual limestone is the Oligocene one (Amuri B), underlain by Runangan and Kaiatan fucoidal glauconitic marl and sandstone, followed by glauconitic marl that ranges in age from Upper Bortonian down to Mangaorapan and possibly Wai-

pawan; this glauconitic marl alone is the age representative of the type Amuri limestone. At Kaikoura Peninsula, no samples from the higher part of the marl and limestone have yet been seen, but the truncation there renders it unlikely that Whaingaroan (Amuri B) occurs; two samples from the flint beds there ("near base" and "five feet from top") both gave Piripauan microfaunas, and Mr. Macpherson's sample from above this (see p. 282) was of Waipawan age.

The outstanding conclusion from this is that what Mr. Macpherson has called "Amuri limestone," with inverted commas, throughout this paper is the age equivalent of the true Amuri limestone of the type section (Lower to Middle Eocene). What he refers to as Amuri Limestone, without inverted commas is a different bed, of Lower Oligocene age, and developed only in the sections to the south.

One final point concerns the Onerahi Series. Mr. Macpherson (see p. 286) writes of the lower part of this as Upper Senonian, but recent collecting in North Auckland has shown that Onerahi faunas range from about Mangaorapan to Upper Bortonian, i.e., the Series as a whole is equivalent to the type Amuri limestone. Any Cretaceous samples found are more properly referred to the Otamatea Series. The single fossiliferous sample from beds believed to be Kaeo yielded an approximately Wangaloan microfauna, and would be Danian or possibly Paleocene.

REFERENCES

FINLAY, H. J. (1940): *Trans. Roy. Soc. N.Z.*, *70*, 91.

ONGLEY, M. and MACPHERSON, E. O. (1928): *N.Z. Geol. Surv. Bull. 30.*

QUENNELL, A. M. and BROWN, D. A.: (1937): *N.Z. Geol. Surv.*, 31st An. Rpt.

BROTZEN, F. (1944): *Sver. Geol. Unders., Ser. C*, No. 465, 44.

TIME SERVICE EQUIPMENT AT THE DOMINION OBSERVATORY

By G. A. EIBY, Dominion Observatory, Wellington

(*Received for publication, 1st September, 1947*)

Summary

A description is given of the time service equipment at the Dominion Observatory, and in particular of the new electrical wiring and relay system.

Photographs and circuit diagrams of certain parts of the equipment are given.

The capabilities of the apparatus and possible extension are considered, together with a brief historical account of the growth of the service.

INTRODUCTION

THE Dominion Observatory, Wellington, is the authority responsible for the determination of correct time in New Zealand, and for its distribution to the public. Up to the present time, there has been no demand for signals of the highest accuracy, and it is found sufficient to transmit signals for which an accuracy within 0.25 sec. is claimed.

This is more than adequate for civil purposes, and for the needs of mariners. For scientific purposes however, it is becoming increasingly desirable to have accurate standards of time and frequency available in New Zealand.

In general, the signals transmitted have a better degree of accuracy than that claimed above, but in the absence of a really modern standard clock, large errors sometimes arise when continuous checks cannot be maintained. These would invalidate a claim to higher accuracy. It should be noted that the error quoted by many observatories is an average error. The value of the average error for the Dominion Observatory signals would be well under 0.1 sec., and was actually 0.06 sec. for the period May to July, 1947. Corrections to any signal can be obtained from the Observatory on special request and these enable checks to within 0.02 sec. or better to be made.

The chief demands for correct time in New Zealand, apart from those of the general public, come from shipping, the railways, post offices and broadcasting stations, and also from the chain of seismological stations maintained by the Observatory. Other time service work undertaken includes the rating of marine chronometers and the determination of longitude by transit observations.

This paper gives an account of new apparatus recently installed to facilitate this work.

BRIEF HISTORY OF THE SERVICE

The Observatory equipment was originally installed in order to provide a service for civil and nautical purposes. Observations for determining the clock errors were made with the transit instrument and the signals were given by extinguishing coloured lights on a mast outside the Observatory, and by telegraph to the Post Office in Featherston Street. These signals were at first confined to Wellington, but by the early part of this century, arrangements had been made to telegraph the signal to any part of the country. In 1914 telephone facilities were added, and within the next few years, time balls and lights were established at Auckland and Lyttelton; 1917 brought transmission of signals by wireless (1). These could be transmitted from Awanui Radio at 10 h. G.M.T. on a wavelength of 2,000 metres, but it was necessary to make special arrangement with the Observatory when they were required. In 1920 regular signals were sent from Wellington Radio on 600 metres each Tuesday and Friday at 9 h. G.M.T. "provided satisfactory observations had been made" (2). The signals were eventually made daily, and light signals and time balls became obsolete. Radio signals are now sent at frequent intervals over the normal broadcasting system, as well as from Wellington Radio at 23 h. G.M.T. A full account of signals now transmitted is to be found in the current Time Service Bulletin (3).

The Transit Instrument dates from the earliest period of the Observatory—certainly before 1883 (4) and the clocks from the same period. Clocks 1, 3, 5, and 6 are by Dent and clocks 2 and 4 by John Moore and Sons. At least one of these clocks dates from before 1870, and the two best were described by Adams (5) in 1926 as "not as good as modern precision clocks". This verdict was given before the introduction of either the Shortt Free Pendulum or the Quartz Crystal Oscillator as timekeepers, although Riefler had made considerable improvements to escapement clocks prior to World War I.

Although this equipment was completely satisfactory for signalling by light and time ball, the introduction of radio led to repeated modification, and the installation of many separate electrical circuits. At no time was the system redesigned from the beginning to cope with the new requirements. In consequence, it was often uncertain in action, lacked ease in operation, and was difficult to maintain. By 1939 insulation failures in inaccessible corners, caused by the age of the wiring, became frequent. Three temporary switchboards were introduced to replace the more unsatisfactory portions of the wiring. The old wiring had to be left in place to avoid further derangement of those parts still in use. The new boards suffered from the disadvantages common to any system designed for piece by piece replacement of an old one. Many bad features were retained owing to the difficulty of changing over without interruption to the service. Not the least of these annoyances was the frequent journeying from clockroom to transit room and back again necessitated by even the commonest routine duties.

About this time, the author constructed a free pendulum, which operated in conjunction with No. 13, a Synchronome slave clock secured a few years previously. This combination, although roughly constructed, surpassed the performance of No. 2, previously the best clock, and proved valuable during the war years. It was dismantled last year in order to allow redesign and more workmanlike construction. This project was interrupted by the designing and installation of the switchboard to be described.

World War II brought an increased demand for time, resulting in a decision to abandon the wiring system and switchboards then in use and to reorganize the whole system. The many wartime delays held up the design work until the middle of 1946 and work was not begun on the installation until early 1947. Some minor circuits still await completion owing to lack of suitable cable, but the switchboard was placed in operation in June, and the associated desk equipment the following month.

DESIGN REQUIREMENTS

The equipment now in use provides facilities for four main types of operation—clock comparisons, reception of radio time signals, transit observations, and the distribution of time.

The clock comparison process consists of a measurement of the errors of all the timepieces of the Observatory relative to the signal clock in use. This enables a check to be kept upon the rate of each timepiece and an extrapolation of the error graph of the signal clock itself to be made. Upon the success of this extrapolation depends the accuracy of the transmitted signals.

Radio time signals are picked up on an HRO communications receiver, and are recorded against both the standard sidereal clock and the mean time signal clock. The signals most commonly used are those of the Naval Astronomical Observatory, Washington, and the Bureau International de l'Heure, Paris. Difficulties arise with these signals owing to the uncertainty in travel time of short wave radio signals. Several observations scattered in time are therefore necessary before ascribing small errors to the clocks. This makes extrapolation of rate more difficult. These difficulties can be minimised by using ultra long wave signals, and arrangements are being made to receive signals radiated on 16 kc. With the help of these it is hoped to make a study of

radio travel times. This will improve the accuracy with which our longitude is known, and consequently the absolute accuracy of out time signals.

The 3 in. transit telescope is fitted with an impersonal micrometer, and is housed in the same room as the radio apparatus. A description of it is given by Adams (4).

Time signals are transmitted daily, both at frequent intervals over the normal broadcasting system, and from station ZLW at 23 h. G.M.T. on a frequency of 500 kc. (3). Bulletins giving the latest details of these signals are published periodically by the Observatory. In addition to the radio signals, a signal is transmitted by land line to all telegraph offices, and to all North Island railway stations at 9 a.m. daily. This signal consists of a three-second dash, which is also used to actuate the seismograph timing shutters..

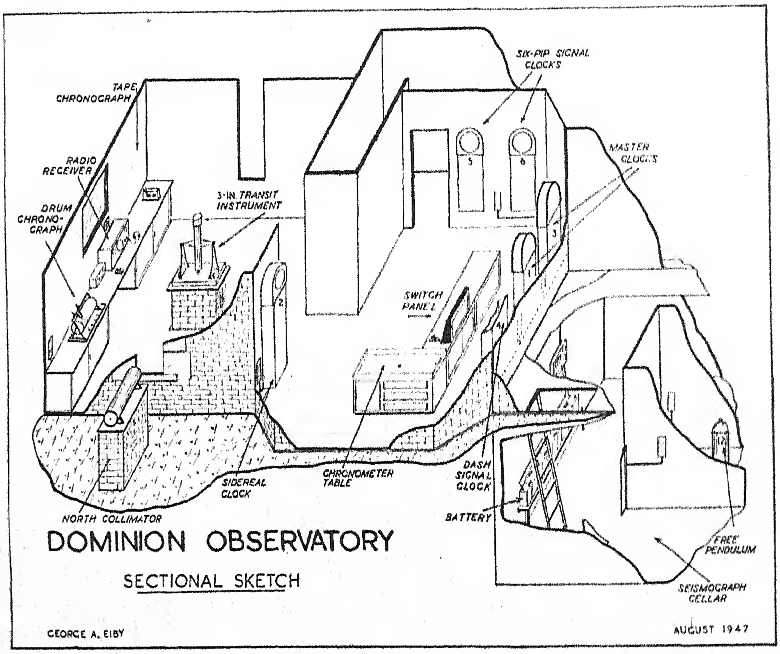


FIG. 1.—Sectional Sketch of the Observatory from the North West.

From the above brief outline of Observatory procedure, it will be apparent that the switching must provide for a rapid re-arrangement of circuits since the same clock or chronograph may be required in quick succession for transmission, reception, or comparison. The functions have therefore been divided into two main groups. The first, that of transmission and clock comparison, is centralized in the clockroom, and the second, that of time determination, in the transit room (see Fig. 1).

In the past, the maintenance of the equipment has been attended to by the Observatory staff, which includes neither an electrician nor a mechanic. It had therefore to be borne in mind that the apparatus should require little maintenance, should be strong enough to withstand accidental mishandling, should be easily accessible, and should allow the connection of additional equipment without soldering in awkward places. Alterations to clocks, chronographs etc., must not necessitate

wiring changes which involve long cable runs from one part of the building to another. Since any outside assistance in maintaining the circuits would probably require someone acquainted with telephone relays, the circuits and wiring diagrams have been made to conform as closely as possible to Post Office practice.

POWER SUPPLY

All the equipment with the exception of certain indicating buzzers, derives its power from alkaline cells. There are two banks of these each making up a 25 v. battery of 120 amp. hr. capacity. Either bank may be brought into operation instantly, by means of a four pole double throw knife switch, which also connects charging leads to the set not in use. With the switch is associated an ammeter and a voltmeter. The whole battery system is mounted on a stout wooden bench in the basement (see Fig. 1). Connection with the clockroom is by 7/.029 V.I.R. cable run in conduit.

These alkaline cells have provided power for the Observatory circuits for nearly forty years. In the past, however, each individual circuit had its own bank of cells. The resulting multiplicity of voltages often led to confusion, and battery maintenance was apt to suffer in the case of the more inaccessible cells. The sturdiness of this type of cell and the high rate at which it can be charged have made it especially suitable for use under Observatory conditions.

WIRING

The subsidiary wiring, with some minor exceptions, has been carried out in multi-pair lead-covered cable. Terminal boxes have been placed in every part of the building where circuits are likely to be required. and also in two outbuildings, the Altazimuth Dome and No. 2 Transit House. This last also houses the Imamura Strong-motion Seismograph. The boxes are indicated on the sectional sketch (Fig. 1) by shaded rectangles. There are altogether eleven boxes, each having provision for either 12 or 25 pairs. Some pairs are paralleled in several boxes, giving intercommunication without connection to the central board. The total number of circuits available is 80, or correspondingly more when earth returns are employed. The far end of each circuit is connected to one of four 20×2 terminal blocks in the rear of the clockroom switchboard. In addition there are two other 20×2 blocks, which terminate the circuits involving switchboard components (Fig. 4). A circuit from one part of the building to another, or from the switching equipment to any part of the building can then be made by soldering short "jumpers" from one tag to another. A completely new piece of equipment can thus be added to the system, or an old circuit can be modified, in a very short time.

The cables to the outhouses are run in ordinary $\frac{3}{4}$ in. waterpipe.

SWITCHBOARD

The clockroom switchboard, as can be seen in the sketch, forms an integral part of an L-shaped desk, at which all clock comparisons are carried out, and from which the transmission of all signals is controlled. The short limb of the L forms the chronometer table, whilst the long one is intended to carry a chronograph and the transmitter for the time

signal "intermediates". These are at present sent from a hand key which can be plugged into the front of the board. At the end of the chronometer table is a jack, into which a lead from the chronometer providing seismograph timing signals is plugged, and in the centre of it a jack for a telephone receiver. This is connected to a simple microphone, consisting of two carbon rods across which rests a third. This

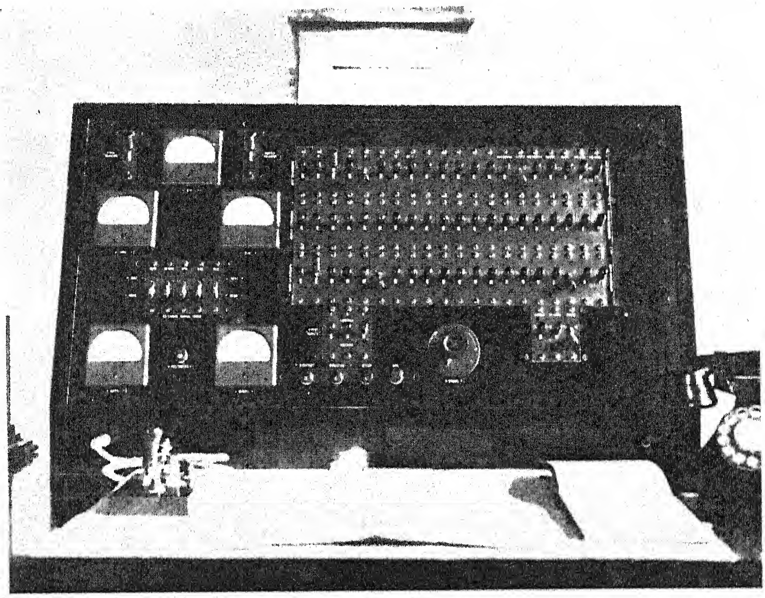


FIG. 2.—Rear View of Main Switch Panel, Top portion.

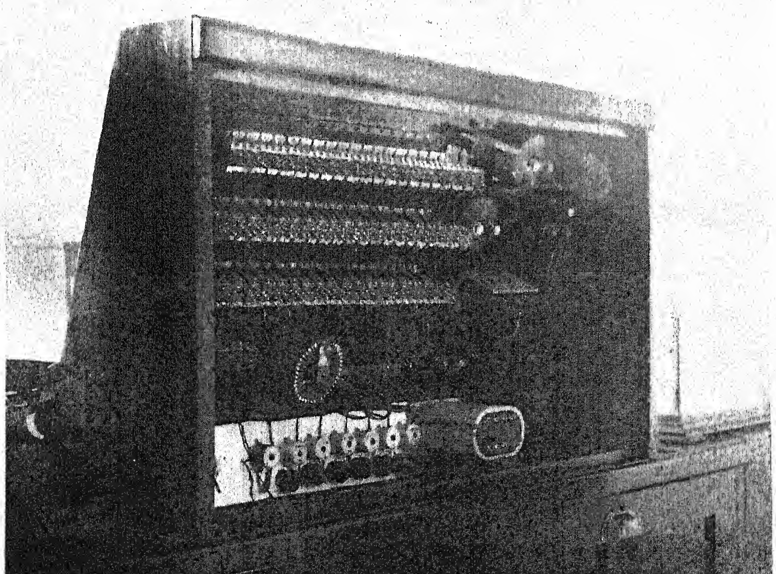


FIG. 3.—Rear View of Main Switch Panel, Lower portion.

microphone is fixed inside the case of the signal clock, and reproduces its ticking for rapid "eye and ear" comparison with the chronometers. The switches for all circuits are placed on the sloping panel, and the associated relay equipment is reached by removing panels at the rear of the desk (see Figs. 2 and 3). The sectional plan gives a clear idea of the location of the different clocks, chronographs, etc.

Clocks 4, 5, and 6 are signal transmitters, and are synchronized to either Clock 1 or Clock 3 as described later. Duplication is necessary to allow for overhaul or in case of breakdown. Clock 4 sends a 3 sec. dash for seismograph timing, and has no duplicate. Clocks 5 and 6 send a 6 pip signal. No. 2 is the standard sidereal clock, and is fitted with a system of mercury contacts (6), which give a signal each second for use on

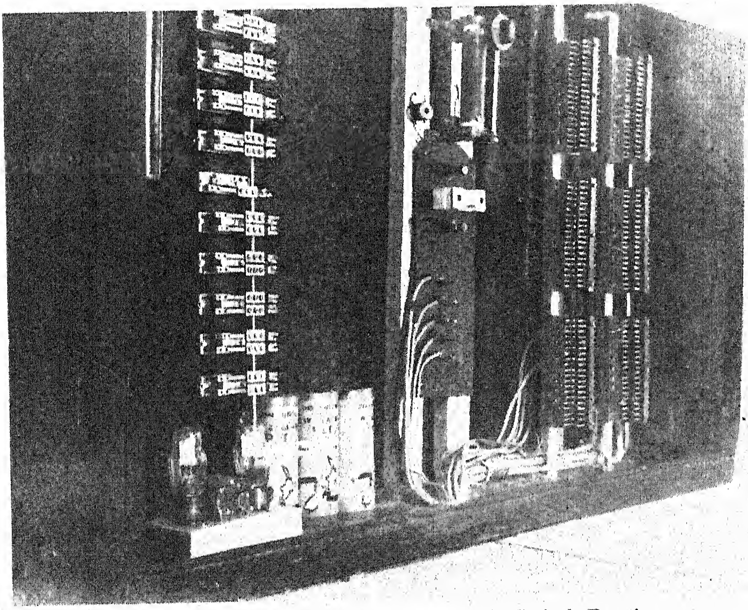


FIG. 4.—Front view of the Main Switch Panel.

the chronographs. Clock 12 is the free pendulum clock at present under re-construction. In addition, two circuits have been provided to carry impulses from two photoelectric relays, one giving mean time seconds from the signal clock, and the other giving sidereal seconds from the free pendulum.

A front view of the switch panel is seen in Fig. 4. The three uppermost meters on the left hand side are in the signal circuits to the G.P.O., 2YA and ZLW, and on either side are the selector keys for the signal clocks and master clocks respectively. The central bank of switches controls the outgoing signals. Each has three positions as described in the "circuit" section below. The lower left hand meter shows the battery voltage when the associated push is depressed and the right hand one shows the current pulse in the synchronizing circuit. The three long banks of keys on the right hand side of the board control the chronographs, one bank to each ; and below them are two banks of

three " every minute " switches on the right and " G.B. Clock ", " No. 2 Relay " and " Phone Bell " on the left. Between them is the rheostat for adjusting synchronizing currents. Two of the pushes at the bottom control the office bells, a third the signal clock microphone and the fourth the circuit from No. 2 clock to the chronograph, allowing a known second to be identified on the record.

SYNCHRONIZING CIRCUIT

The signal clocks are kept in step with the master by means of a simple electromagnetic arrangement. Each of the signal clocks carries at the lower extremity of its pendulum a small armature of soft iron. At one limit of its swing, this armature passes between the poles of an electromagnet. This magnet is energized by the master clock at each swing, and the pendulum made to execute forced vibrations. The arrangement of the master clock is as follows. To the upper end of the pendulum is fixed a cross arm, carrying a pin at its outer extremity. The pin can dip once each swing into an insulated metal cup, containing a quantity of mercury covered with paraffin. This contact completes the circuit of the electromagnets.

The system will cope with quite large changes in the rate of the master clock, but variations of more than 0.1 sec. in 10 minutes are inadvisable. Failure to synchronize usually results in stoppage of the clock. These rapid changes are occasionally needed in order to correct the signal clocks before signal transmission. Some modification was recently made to the form of the magnets to prevent damage to the pendulum suspension springs by bumping in the event of a local earthquake. There seems to be room, however, for a closer investigation of the limits of this system of synchronization.

The circuit normally operates with a current of 24 ma. and a rheostat is provided on the panel to cope with small variations in battery voltage. In addition a large cylindrical slide resistance in the rear of the board enables the removal of a clock from the circuit for overhaul to be compensated. This can be seen in the centre of Fig. 3.

Since failure of the synchronizing circuit would cause the transmission of incorrect signals, it has been run in separate lead cable carrying no other circuits. This makes for the maximum strength and ease of location. The circuit is specially terminated on a sub-panel immediately under the cylindrical rheostat.

SIGNAL CIRCUITS

A simplified version of a signal circuit is shown in Fig. 5. Only two signal clocks, Nos. 5 and 6, are shown, and three of the outputs, to ZLW, 2YA, and to the telephone signal circuit. All other circuits may be regarded as approximating to one or other of these types.

With each clock is associated a type 3,000 telephone relay. These are located in the rear of the clockroom desk, in the compartment under the switch panel, and can be seen in Fig. 3 on the left hand side. No observation is made upon a clock, or signal sent from one, which does not include the operation of the relay. The necessity for considering relay lags is consequently removed since these are incorporated in every observation, and may be regarded as constant so long as the battery voltage does not vary appreciably. This is kept under constant observation.

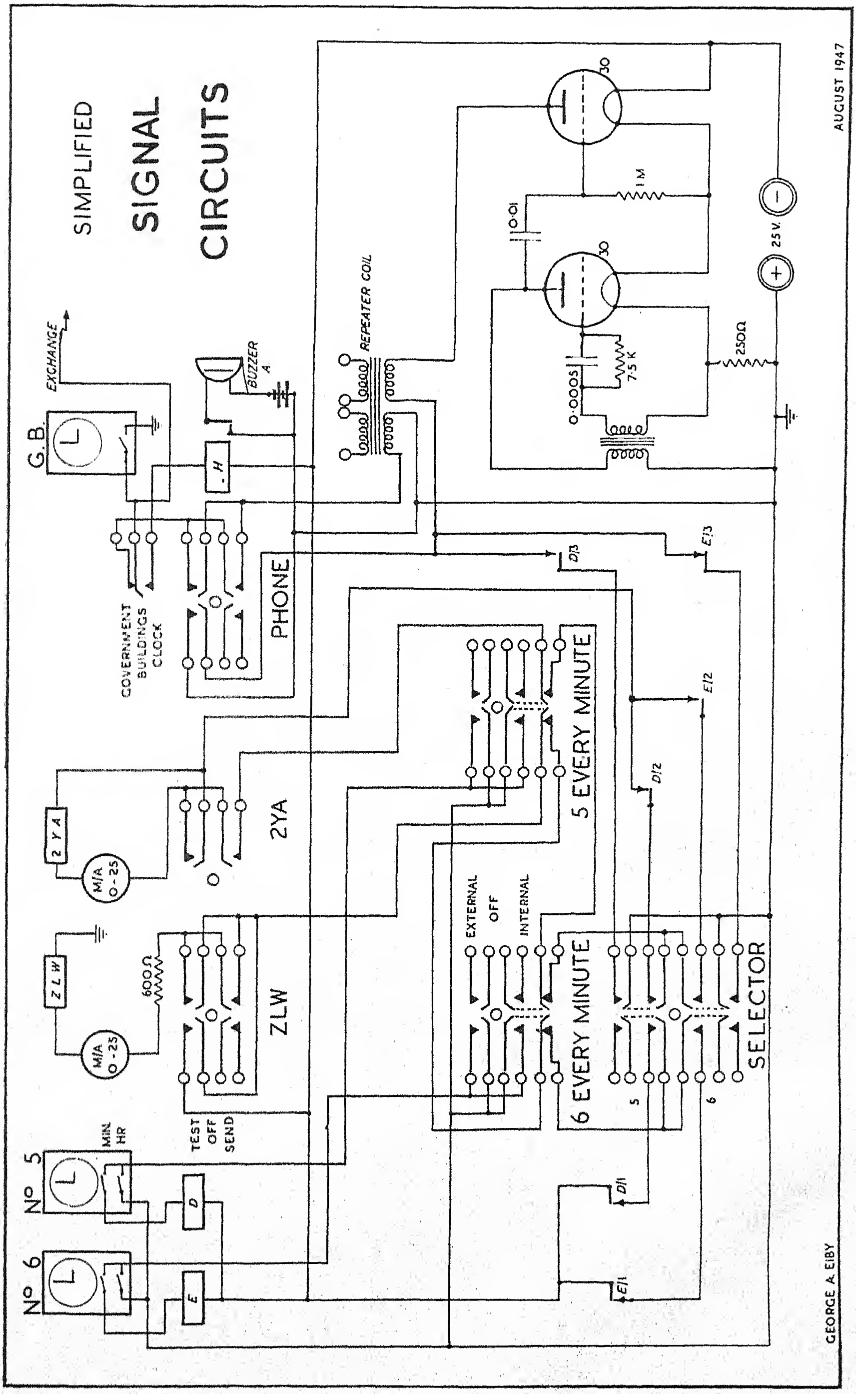


FIG. 5.—Simplified Time Signal Circuits.

Each relay carries six contacts, and serves two purposes. The first is to keep high currents out of the clock contacts, which are small and delicate in order to have the least possible effect on the rate of the clock, and the second to multiply the number of circuits which can be controlled by a single source. All the relays remain permanently connected, with the exception of that associated with No. 2 clock. This can be switched off by a key on the lower right hand side of the board, thus preventing too rapid oxidation of the mercury contacts. These cannot receive attention without altering the rate of the clock.

The signal clocks contain two contacts; " MIN " which sends the signal each minute, and " HR " which closes during certain selected minutes of each hour. The two are connected in series, and when both close, the associated relay (D for clock 5 and E for clock 6) is energized, closing all its associated contacts. Each clock has an " every minute " switch, mounted on the switch panel as described above. These, as can be seen, are three position switches, and are inoperative in the central position. When in the down position, the " HR " contact on the clock is short circuited. This allows the signal to energize the relay each minute. At the same time, the circuits to ZLW and 2YA are broken, so that spurious signals are not transmitted. This is known as the " internal " position, and is used to secure the extra signals needed for comparisons and in recording overseas radio signals. The up or " external " position also shorts the " HR " contact, but does not break the outgoing circuits. It is thus possible to transmit extra signals at any time for test purposes. Note that operation of either " every minute " switch on the internal position will break the signal circuits, whether or not that clock is connected to the outside lines.

Outgoing signals leave the Observatory in an underground telephone cable, and the different users require different kinds of signal pulse. ZLW, for instance uses an earth return and requires a current of 25 ma. to operate the transmitting relay. This has to be supplied from the Observatory battery. 2YA has its own audio oscillator and power supply and requires only the closing of a two-wire circuit. The telephone signal circuit, which gives a signal by telephone for scientific purposes, is fed with an audio frequency signal generated at the Observatory. The three keys near the top of Fig. 5, marked " ZLW ", " 2YA ", and " Phone ", are test/send switches. The " test " position sends a continuous signal down the line, the central position is off, and the " send " position is that for normal operation. Circuits fed with 6 pip signals pass through the " signal selector " also. This is a two-way key which connects the circuits all to the contacts of relay D, operated by clock 5, or all to those of relay E, operated by clock 6. No difficulty should be experienced in tracing the complete operation of these from the circuit diagram.

The " Phone " circuit is more complex. The line itself passes through the switch " G.B. Clock " (shown in its normal position), and via a normal test/send switch to one winding of a repeater coil, the other side of which is grounded. Into another coil of this repeater is injected a six-pip 1,000 cycle audio signal from a local oscillator which is triggered by relay D or relay E according to the position of the selector switch. Both filament and anode voltages are derived from the central battery. The filaments are connected in series and are run at a lower current than normal, in order to extend their life. The oscillator works continuously, but anode voltage is applied to the

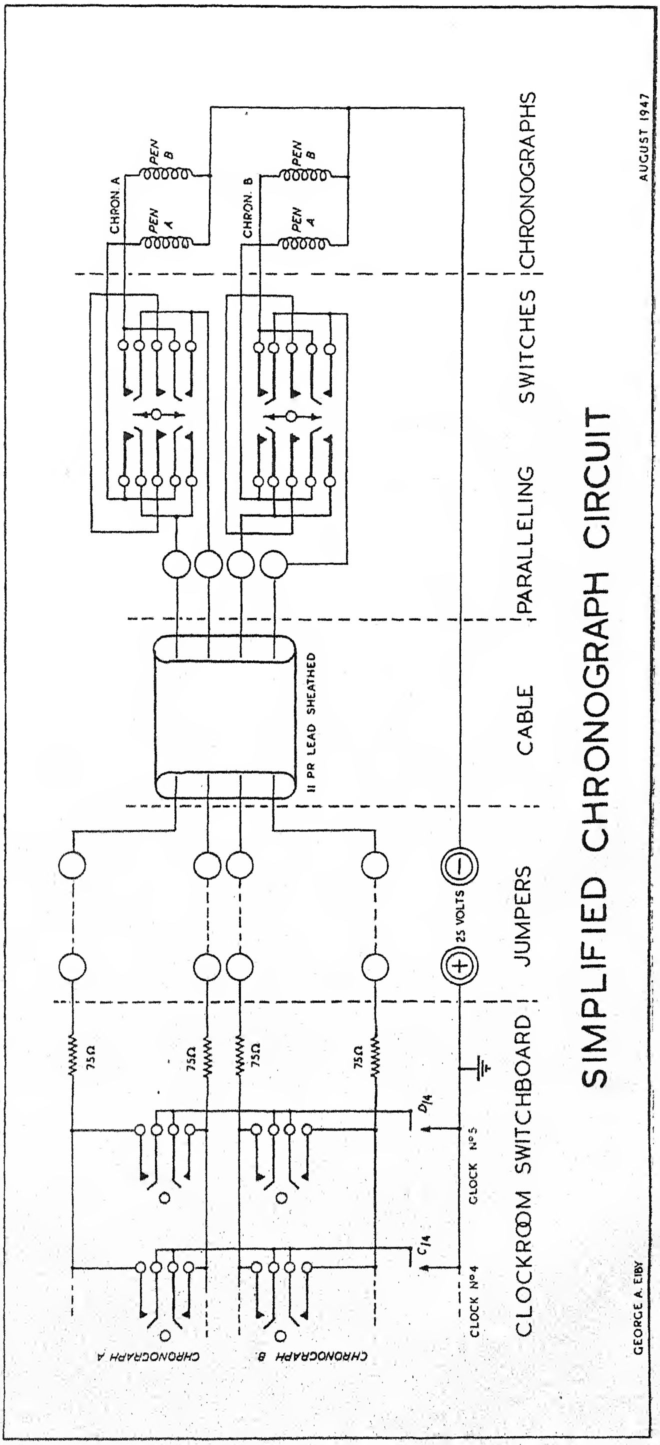


Fig. 6.—Simplified Chronograph Circuits.

amplifier only when the relay closes or the test/send switch is in the "test" position. This has been found to give a clear note free from key clicks and sufficiently loud to overcome the considerable noise and "cross-talk" sometimes experienced on this telephone line.

When the "G.B. Clock" switch is moved to the down position, the line is disconnected from the repeater coil, and joined to a circuit consisting of the battery, the operating coil of relay G, and a contact on the Government Buildings clock which closes when the clock chimes. This signal operates buzzer A in the Observatory switchboard, and enables the error of the clock to be observed.

It should be noted that changeover of the selector switch does not affect the operation of the relays, the selection being one of controlled circuits, and not of relay windings. Chronograph observations of the signal clock not in use can therefore be made without affecting the signal circuit. This valuable feature was not included in the previous system, a single relay being used for transmission of signals from either clock. This was a specially designed low lag relay, but experience confirms the opinion that associating a relay with its own clock leads to fewer errors of observation.

CHRONOGRAPHS

The Observatory has three chronographs and the switchboard makes provision for 20 different signal sources. The simplified circuit (Fig. 6) shows only two, and two different signal sources, the relays C and D, associated with Clocks 4 and 5 respectively. The chronograph switches have three positions, the centre one being off, the "up" connecting one pen, and the "down" the other. Each horizontal row of switches controls one chronograph and each vertical row one signal source. The lines to the chronograph pens contain 75 ohm limiting resistors, and connection is made by tag jumpers to wires in one of the lead cables. At the far end, the circuits pass through paralleling switches, one associated with each instrument. In addition to the central "off" position and the down "on", these keys have a "parallel" position which feeds all signals to both pens. This facilitates the determination of any errors due to pen parallax or to difference in lag between the two pens. By turning off this switch, a chronograph can be set up for, say, radio signal reception and turned on when required at the paralleling switch, without reference to the main switchboard. This is particularly useful in the case of the transit room chronographs.

CONCLUSIONS

The electrical circuits now installed in the Observatory seem to be free from most of the inconveniences of the past, and to be able to cope with normal future expansion for some time to come. Although the service which can now be provided is adequate for civil purposes, the demands of longitude, frequency, radio propagation and seismological work would seem to require greater accuracy in the near future. This can be obtained within the framework of the existing system by the installation of at least one modern precision clock. This should preferably be of the quartz crystal oscillator type, for although the length of the run obtained is shorter than that of free pendulums under normal operations, susceptibility of the latter to interference by local earthquakes is a disadvantage. Such additions would both facilitate the maintenance of the civil time service, and open up possibilities of research programmes which cannot at present be undertaken for lack of precision time or frequency standards.

References

(1) (1917): *N.Z. Gaz., No. 55* (also issued as *Dom. Observ. Bull. T-1*).

(2) (1920): *Dom. Observ. Bull. T-2*.

(3) Hayes, R. C. (1942): "N.Z. Mean Time." *N.Z. Off. Year Book*, 1942 (also issued as *Dom. Observ. Bull. T-17*).

(4) Adams, C. E. (1926): "International Longitude Observations, 1926." *Dom. Observ. Bull., 69* (A-45), p. 6.

(5) Adams, C. E.: *Loc. cit.*, p. 14.

(6) Adams, C. E.: *Loc. cit.*, p. 15.

A GENERAL PURPOSE RECORDING APPARATUS

By W. G. Whittleston and J. M. Ziman, Animal Research Station, Department of Agriculture, Ruakura

(*Received for publication, 7th July, 1947*)

Summary

A recording instrument is described which is based on an A.C. bridge network combined with a balancing motor controlled by phase discriminating relays. A discussion on the requirements for an anti-hunt inching mechanism is included and the application of the inching principle to the recording apparatus described.

Introduction

The apparatus to be described arose from the need for recording equipment capable of measuring changes in electrical conductivity, small pressure changes and liquid flow rates. Such a range of phenomena suggested the design of a really general purpose recording unit and its description is prompted by the fact that its usefulness may be of value to others.

After some consideration the phase discriminating relay mechanism used during the war for auto-pilot mechanisms (1) seemed to form a good basis to start from. This principle is simple and sure. The biggest problem was to make a simple anti-hunting mechanism.

One of the requirements of the recorder was that it be small and portable. This ruled out several possible mechanisms but that to be described seems very satisfactory and capable of a range of adjustments and applications.

The subject will be treated in three sections :—

(1) A theoretical discussion on the use of "inching" mechanisms for anti-hunting purposes.

(2) A description of the recorder incorporating the phase discriminating relay principle and a simple inching mechanism.

(3) Applications of the apparatus. (To be published later.)

Part I. Description of Apparatus and Consideration of Principles Involved in its Application

Many recording and controlling devices may be described in the following general terms :

C A O B D

An arm with a contact slides along a resistor C D. In a recording instrument this arm is driven by a small motor and bears a pen or pointer. At any given moment a point O represents the balance point. Thus, in a milk flow recorder it is the balance position of the bridge whose other arm is the potentiometer coupled to the tank float. When the contact is to the left of a point A, or to the right of B, a relay closes and actuates the motor, driving the contact arm back towards O. As O moves in accordance with the variable that is being recorded, A and B move with it, and the contact and arm are constrained to follow, the pen then tracing out the values of the variable.

However, such an instrument may, in practice, be rendered somewhat insensitive by the finite inertia of the motor. If this is sufficient oscillation or "hunting" phenomena may be found. Thus, the contact reaches A, the motor switches off, but the weight of the moving parts carries the contact past O to B. The motor is then reversed and drives the arm back past O to A. The process repeats itself indefinitely, and the pen leaves a broad trace on the paper.

This effect may be avoided in three ways:—

(1) The gap A B may be widened, thus reducing the sensitivity somewhat.

(2) A resistance or brake may be applied to the motor to prevent it reaching sufficient velocity to carry over the gap.

(3) "Inching" may be employed.

It is this third technique which is the subject of the present discussion. In broad terms, the method consists in having two further relays, at C and D, outside A B, that are actuated when the bridge is somewhat out of balance. With the contact to *the left of C or to the right of* D, the motor runs freely. Between C and A and between B and D the motor is fed with short pulses of current. Between A and B, there is no current to the motor, as before. The effect is to reduce greatly the velocity which the arm can attain near the balance point, preventing it from over-running.

The problem, then, is to determine the values of the duration of the pulses, the time between them, the widths of A B and A C, such that the sensitivity of the instrument shall be at an optimum. It is necessary to calculate these in terms of readily measurable constants of the instrument, and some criteria of sensitivity must be set up.
Let us assume that the mechanical and electrical inertia of the motor and arm may be lumped into a constant m, and the resistance and frictional terms into a constant r. When the current is switched on, the force on the arm is p. The displacement of the contact along C D at time t is then x. We can write down two fundamental equations.

$$m\frac{d^2x}{dt^2} + r\frac{dx}{dt} = p \qquad (1)$$

when the current is on, and

$$m\frac{d^2x}{dt^2} + r\frac{dx}{dt} = o \qquad (2)$$

when the current is off.

(Terms in x are assumed negligible, representing electrical capacities and *stiffness factors.*)

Suppose the velocity in the steady state, i.e., when $\frac{d^2x}{dt^2} = o$ is v.

Then $$v = \frac{p}{r} \qquad (3)$$

Put $$k = \frac{r}{m} \tag{4}$$

and we have $$\frac{d^2x}{dt^2} + k\frac{dx}{dt} = vk \tag{1a}$$

$$\frac{d^2x}{dt^2} + k\frac{dx}{dt} = o \tag{2a}$$

These differential equations may be solved by the usual methods and give $$x = vt - \frac{v}{k}\left[1 - e^{-kt}\right] + \frac{s}{k}\left[1 - e^{-kt}\right] \tag{5}$$

$$\frac{dx}{dt} = v\left[1 - e^{-kt}\right] + se^{-kt} \tag{6}$$

for (1a) and $$x = \frac{s}{k}\left[1 - e^{-kt}\right] \tag{7}$$

$$\frac{dx}{dt} = se^{-kt} \tag{8}$$

for (2a), where s is the velocity when $t = o$, $x = o$.

Let the current now be fed in pulses of time length t_2 with a pause of duration t_1, between. Then, whatever the initial velocity of the arm, after some time the velocity settles down to a steady value about which it fluctuates as the pulses are fed in. The maximum velocity, which we shall call V_{max} occurs at the end of a pulse. If S is the velocity at the beginning of a pulse, we have from (6) and (8)

$$v_{max} = v\left[1 - e^{-kt_2}\right] + se^{-kt_2} \tag{9}$$

and $$s = v_{max}\, e^{-kt_1} \tag{10}$$

i.e., $$v_{max} = \frac{v\left[1 - e^{-kt_2}\right]}{\left[1 - e^{-kt_1}\, e^{-kt_2}\right]} \tag{11}$$

If the current is now cut off, the arm will move a distance $\frac{v_{max}}{k}$, by equation (7). This distance must be less than the distance AB = 2w.

Thus $$2w > \frac{v\left[1 - e^{-kt_2}\right]}{k\left[1 - e^{-kt_1}\, e^{-kt_2}\right]} \tag{12}$$

Put $kt_1 = \alpha$, $kt_2 = \beta$, α and β are then the ratios of the "off" and "on" times, respectively, to the time for the velocity of the motor to fall to $\frac{1}{e}$ of its value when the current is cut off. We must then have

$$\frac{2wk}{v} > \rho \tag{13}$$

where $$\rho = \frac{\left[1 - e^{-\alpha}\right]}{\left[1 - e^{-(\alpha + \beta)}\right]} \tag{14}$$

The significance of ρ is that it is a pure number, whose value is determined by the constants of the motor and inching mechanisms, and which must be less than the ratio of the width A B of the neutral gap to the distance which the arm moves when the current is cut off, in order that oscillations should not occur. Curves of constant ρ are plotted in Fig. 1, with α and β as variables.

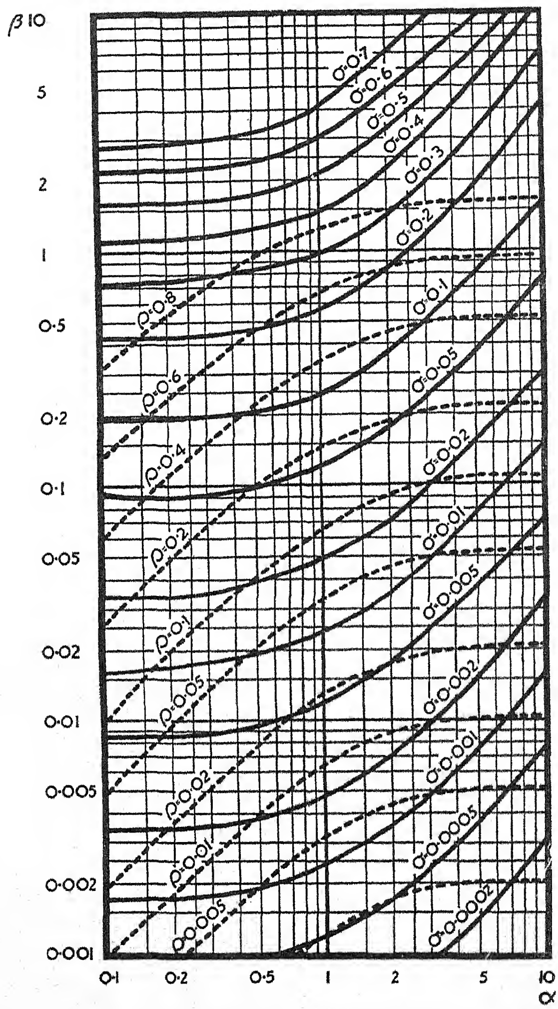


FIG. 1.—Curves of constant σ and ρ with varying α and β.

It is necessary now to find some further sensitivity criterion besides the width 2w. For this, a form of "velocity response" is suggested. Consider the balance point O moving so that relay A closes. This may be assumed to occur, on the average, in the middle of the off period of the pulsing mechanism. The arm will thus stay at rest for a time $\frac{t_1}{2}$, then be given a "kick". The distance d travelled as a result of this will be, from (5), (6) and (7)

$$d = vt_2 - \frac{v}{k}\left[1 - e^{-kt_2}\right] + \frac{v}{k}\left[1 - e^{-kt_2}\right]\left[1 - e^{-kt_1}\right]$$

$$= vt_2 - \frac{v}{k}e^{-kt_1}\left[1 - e^{-kt_2}\right] \qquad (15)$$

We can say that this occurs, on the average, in a time $\frac{t_1}{2} + t_2 + t_1$.

In other words, the bridge is brought back into balance with a single "kick" if the velocity of O does not exceed q where

$$q = \frac{d}{\frac{3t_1}{2} + t_2} \tag{16}$$

Now put $\sigma = \frac{q}{v}$. Then

$$\sigma = \frac{1}{\frac{3\alpha}{2} + \beta} \left[\beta - e^{-\alpha}\left(1 - e^{-\beta}\right)\right] \tag{17}$$

σ is a number of zero dimensions, and represents the ratio of the greatest velocity which can be recorded accurately to the tracking velocity of the arm when the motor is running freely. In Fig. 1, contours of constant σ are plotted for values of α and β.

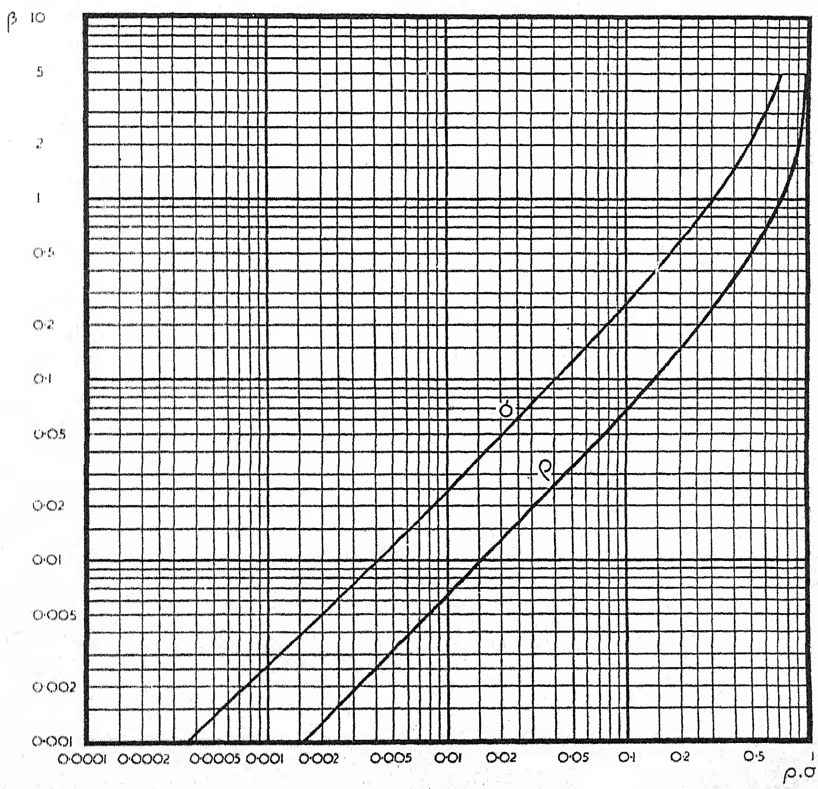


FIG. 2.—σ and ρ plotted against β.

Consideration of Fig. 1 now shows that maximum values of σ are associated with minima of ρ about the line $\alpha = 1$. This, then, will be the best value of α, to be used when possible. Fig. 2 shows the values of ρ and σ for this value of α.

Finally, it is necessary to calculate the length l of C A. Consider the motor stopped at C, the arm continuing under its own momentum for a distance a for a time μt_1, where $\mu < 1$, then given a pulse of duration

t_2, during which it travels a distance b, and finally coming to rest after travelling a further distance c. The total distance travelled is a + b + c

where $$a = \frac{v}{k}\left[1 - e^{-\mu k t_1}\right] \qquad (18)$$

$$b = vt_2 - \frac{v}{k}\left[1 - e^{-kt_2}\right] + \frac{v}{k} e^{-\mu k t_1}\left[1 - e^{-kt_2}\right] \qquad (19)$$

$$c = \frac{v}{k}\left[1 - e^{-kt_2}\right] + \frac{v}{k} e^{-kt_2} e^{-\mu k t_1} \qquad (20)$$

from equations (5), (6), (7), (8).

i.e., $$a + b + c = \frac{v}{k}(1 + \beta) \qquad (21)$$

This should be the distance C O, for then the time taken in crossing C A will contain only one pulse, i.e.,

$$l + w = \frac{v}{k}(1 + \beta) \qquad (22)$$

Whence knowing w and having decided on β we can calculate l.

If, for practical reasons, the value of α must be made somewhat less than 1, the following expressions, which may be derived by considering the effect of a number of pulses acting on the motor as the contact travels from C to A, may be used.

The criterion (13) becomes

$$\frac{2kw}{v} > \rho\left[1 + \frac{(1 - e^{-\alpha})}{(e^{\beta} - 1)} e^{-n(\alpha + \beta)}\right] \qquad (23)$$

whilst (22) becomes

$$\frac{kl}{v} = n\left[\beta + e^{-\alpha}\left(1 - e^{-\beta}\right)\right] + \frac{(1 - e^{-\alpha})}{(e^{\alpha + \beta} - 1)}\left[1 - e^{-n(\alpha + \beta)}\right] \qquad (24)$$

The procedure is, having decided w, α and β, to determine n from (23) and then find l by substituting in (24). But this is only valid when n is at least greater than 1, and cannot be relied on for say n less than 0.5.

The practical determination of the assumed constants k and v is quite simple. v is obtained by measuring the time the arm takes to "track" a measured distance at full speed. $\frac{v}{k}$ is the distance the arm travels after the current is cut off when running at full speed. w is easily measured, and may usually be varied by altering the sensitivity of the electrical circuits.

To determine the optimum conditions for "inching" without "hunting" in a given machine, measure k and v, decide on w, and calculate $\frac{kw}{v}$. Find a value of ρ just less than this and determine the corresponding value of β in Fig. 2. Then $t_1 = \frac{1}{k}$ and $t_2 = \frac{\beta}{k}$. l may be found from (22). The "Velocity response" q is given by σv, σ being read off on Fig. 2 from the appropriate value of β. Alternatively q may be predetermined, and a minimum value for w found. Or it may be necessary to use a value of α different from 1, when the necessary conditions are found from Fig. 1 and, if necessary, equations (23) and (24).

Example: In applying these methods to the recorder, we have the following measurements.

The arm travels with a velocity of 15 mm./sec. when the motor runs freely. When the motor is switched off, the arm travels a further 3.5 mm. The relays are both open over a space of 1 mm. at the balance point. Thus $v = 15$ mm./sec. $\frac{v}{k} = 3.5$ mm. $2w = 1$ mm.

Then
$$\frac{2wk}{v} = \frac{1}{3.5} = 0.29$$

Take $\rho = 0.2$, allowing a good margin. With $\alpha = 1$ we have $\beta = .15$. These values give $\sigma = 0.06$, and the maximum velocity which may be recorded accurately is
$$q = \sigma v = 0.06 \times 15 = .9 \text{ mm./sec.}$$

This is adequate for the purpose in hand.

The pulsing mechanism is then arranged so that the current is off for a time
$$t_1 = \frac{\alpha}{k} = \alpha \cdot \frac{v}{k} \cdot \frac{1}{v} = \frac{1 \times 3.5}{15} = .23 \text{ sec.}$$

and on for a time.
$$t_2 = \frac{\beta}{k} = \beta \cdot \frac{v}{k} \cdot \frac{1}{v} = \frac{.15 \times 3.5}{15} = 0.035 \text{ sec.}$$

Finally we have
$$l = \frac{v}{k}(1 + \beta) - w = \frac{v}{k}\left(1 + \beta - \frac{kw}{v}\right) = 3.5\,(1 + .15 - .14) = 3.5 \text{ mm.}$$

The " inching " relays should thus be set to act when the arm is 4 mm. from the balance point.

PART II. THE RECORDING APPARATUS

Fig. 3 gives the circuit diagram of the apparatus. It may be divided for the purpose of discussion into three sections :—

(1) the bridge circuit ; (2) the balancing motor and (3) the phase discriminating relays.

The bridge circuit consists of two wire wound potentiometers R.10 and R.11 fed from a small 6 volt transformer T_2. The balancing motor drives the earthed arm of R.10 while the arm of R.11 is operated by the measuring apparatus, e.g., a pressure operated device or a float mechanism. For some applications R.11 may be replaced by a fixed resistor and a conductivity cell, R.10 being suitably modified. Both resistors may be replaced by variable split stator capacitors. In fact any 50 cycle A.C. bridge network may be employed at this point.

The balancing motor used is a small radio tuning motor whose shading coils L4 and L5 may be shorted by the relay contacts S1 and S2, the direction of rotation of the motor being controlled by whichever contact closes. This motor drives a pen across the paper and moves the arm of R.10.

The out-of-balance voltage from whatever bridge circuit is used is applied to the control grid of the pentode amplifier V4 whose output voltage is applied to the two control grids of the double triode V2. The coils of the relays operating S1 and S2 are in the plate circuits of V2 and receive power from either end of the centre tapped secondary of T1, a small radio transformer. (The plate voltage of the pentode V4 is supplied by the rectifier V1 and the smoothing-circuit R2, C1, C2, from the same transformer secondary). The bias for the grids of V2 is supplied from one wing of the secondary of T1 the "shunt diode" V3 (2) and its associated smoothing circuits R15, C7 and C8. The level of bias is controlled by the potentiometer R7 and the variable resistor R8 together with the rotary switch R.S.

The inching mechanism consists of the rotary switch R.S. driven by the synchronous clock motor which drives the paper through the recorder and the resistor R8. This results in a "square wave" being impressed on the bias voltage applied to V2. This type of inching mechanism is convenient in that it avoids any extra switching mechanism in the motor circuit as the relays supply the intermittent switching. With the relays available the time constants were rather high with the result that the optimum inching frequency being too high for the circuit could not be used. The compromise effected reduces the maximum balancing speed within the inching margin. This point is worth consideration when a choice of relays is possible.

The action of the circuit is as follows: Out-of-balance voltage appearing at R.6 is amplified and applied to V2 whose grids are just biased to cut-off when R.S. is closed. Depending on the phase relations between the original out-of-balance voltage and those of the two ends of the secondary of T1, the alternating voltage on the grids of V2 causes one or other half to conduct thus energising the corresponding relay coil. This causes the motor to run in such a direction that it brings the circuit back into balance. Now, as previously described, if there is no anti-hunt provision, when the sensitivity of the circuit is high the mechanism will hunt. However, as the balancing arm nears the null point the signal on the grids of V2 falls below the level of the swinging bias on these grids and the tube conducts intermittently. The motor thus runs in a series of spurts until the voltage has fallen to such a level that the relay is not energised when R.S. is closed.

The adjustment of the apparatus is effected as follows: R.6 is moved to give no signal on the control grid of V.4. With R.S. closed R.7 is set so that both relays have just dropped out. R.8 is set for the desired inching margin A.B. (Part 1). R.6 is then set for the level of sensitivity required. As can be seen the device is very flexible in that both inching margin and sensitivity are variable over quite a range.

The complete apparatus consists of a chassis carrying the electronic circuits and relays mounted in a box beneath a panel carrying the paper-moving mechanism which is driven by a Venner synchronous clock motor. This latter operates the rotary inching switch. The recording and balancing motor is carried by the lid of the box so that when the lid is opened the pen is lifted from the paper. A third relay is used for the remote control of the paper drive so giving us a convenient flexible recorder for use in the laboratory and in the field.

Applications of the instrument will be described in a subsequent paper.

ACKNOWLEDGMENTS

The writers wish to acknowledge the assistance given by Mr. J. D. Allen of this laboratory who constructed most of the recording apparatus described above.

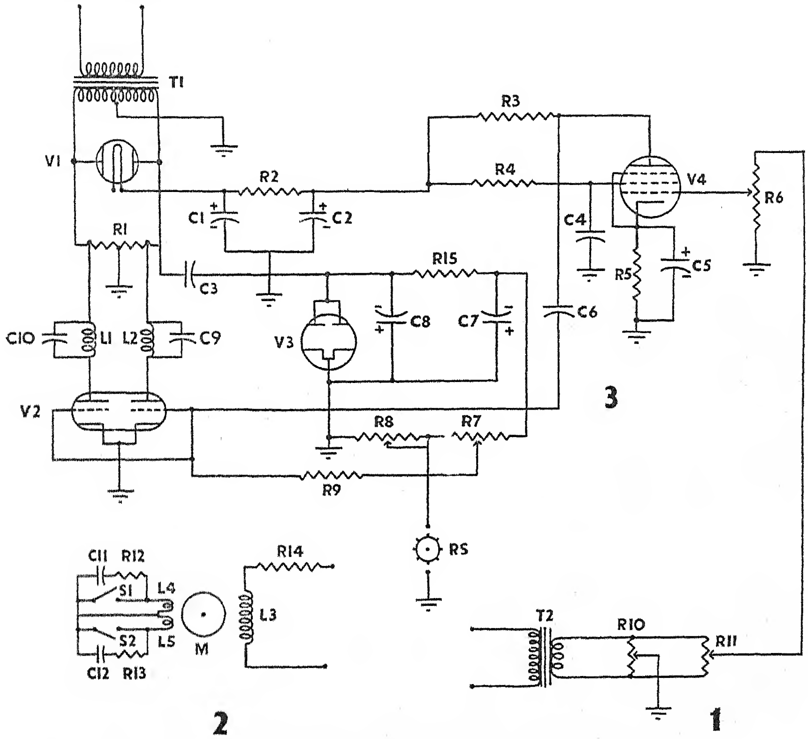


FIG. 3.—Circuit of recording instrument.

TABLE I. COMPONENTS LIST (Fig. 3)

Resistors :	R1	20,000 ohms wire wound 50 watts
	R2	50,000 ohms carbon 2 watts
	R3	500,000 ohms carbon 1 watt
	R4	2,000,000 ohms carbon 1 watt
	R5	1,500 ohms carbon 1 watt
	R6	500,000 ohms carbon potentiometer
	R7	100,000 ohms carbon potentiometer
	R8	100,000 ohms carbon potentiometer
	R9	500,000 ohms carbon 1 watt
	R10	10,000 ohms wire wound potentiometer
	R11	Any suitable bridge arrangement (see text)
	R12, R13	100 ohms carbon 1 watt
	R14	Wire wound adjusted to give desired motor speed
	R15	500,000 ohms carbon 1 watt
Capacitors :	C1, C2, C7, C8	8 mfd electrolytic
	C3, C6	.05 mfd tubular paper
	C4	.25 mfd tubular paper
	C5	25 mfd electrolytic
	C9, C10	.5 mfd tubular paper
	C11, C12	.25 mfd tubular paper

Valves	V1	5Z4 rectifier
	V2	6 SN7GT
	V3	6 X 5
	V4	6 SJ7
Transformers :	T1	Midget radio transformer. 350 - 0 - 350, 6.3, 5.0 v.
	T2	Small 6.3 v. filament transformer
	L1, L2, S1, S2	Telephone type relays 6,000 ohms coils
Balancing motor :	M	Radio tuning drive motor 110 v.

REFERENCES

(1) GILLE, W. H. and SPARROW, H. T. (1944): Electronic autopilot circuits. *Electronics*, *17*, 110.

(2) *Ibid.* (1945): Use of shunt diode for supplying bias. *Electronics*, *18*, 218.

A LABORATORY-BUILT PHOTOELECTRIC COLORIMETER AND FLUORIMETER

By W. A. McGILLIVRAY, Massey Agricultural College, Palmerston North

(*Received for publication, 19th September, 1947*)

Summary

This paper describes a simple combination colorimeter-fluorimeter suitable for general laboratory work. The instrument is inexpensive and easily constructed from readily obtainable components. Designed originally for vitamin assay work the instrument can readily be adapted to other uses. It has been used extensively for the colorimetric estimation of Vitamin A (using the antimony trichloride and glycerol dichlorhydrin methods), carotene and nicotinic acid, for the fluorimetric detremination of thiamin (thiochrome method) and riboflavin and for turbidity measurements (e.g., in certain micro-biological methods).

INTRODUCTION

ALTHOUGH the measurement and comparison of light intensities by means of photoelectric cells has long been an established practice in physics, it has only recently been applied to chemical problems and the introduction of precision photoelectric methods to this field has given a much needed impetus to colorimetric and fluorimetric methods of analysis. Although there still exists considerable difference of opinion as to the relative merits of photoelectric as against visual methods of colour measurement, for most colorimetric work the photoelectric method possesses the advantage of freedom from 'personal error', greater accuracy and reproducibility together with speed, ease of operation and absence of fatigue.

At the same time photoelectric measurements require more critical interpretation than visual and not all colorimetric procedures lend themselves, without modification, to photoelectric methods. Solutions matched photoelectrically are not necessarily matched visually and in particular photoelectric measurements are upset by interfering factors such as turbidity, so that much of the criticism of photoelectric colorimeters should be levelled at particular methods of analysis rather than at photoelectric methods in general.

Following Evelyn's original contribution (1) a large number of designs for photoelectric colorimeters, absorptiometers and fluorimeters have appeared, together with a number of commercial models. Fundamentally all depend on a comparison by means of a photoelectric cell or cells of the amount of light transmitted by an absorption cell containing a solution of the coloured substance to be estimated and a similar cell containing a known amount of the pure substance.

Photocells and Circuits

Of the three main types of photo cells available, only the high vacuum photo-emissive and the barrier layer types have been used to any extent in colorimetry. Gas filled photo-emissive cells are not used since although they possess the advantage of up to ten times the sensitivity of the corresponding high vacuum type, because of ionisation currents, linearity of response is attained only at low applied potentials, i.e., when the cell is really behaving as a vacuum cell.

High vacuum cells possess the advantage of high sensitivity since their output can be amplified to any desired degree by the use of standard radio valves and they are particularly useful when only weak illumination is available. However their use necessitates a stabilized D.C. voltage and the construction of a sufficiently stable amplifier presents difficulties in the way of general design and layout. Unless these conditions are satisfied there is a tendency to drift and to general instability (see later). The use of these tubes is therefore restricted to special applications of colorimetry and by far the greater majority of colorimeters employ the barrier layer type of cell. Although these cells give 2-3 times more output per lumen than the high vacuum photo emissive type, their actual sensitivity is lower since amplification is restricted owing to their low internal resistance. (Although it is generally considered impossible to successfully amplify the output of barrier layer cells, amplifier circuits have been suggested by the manufacturers (2)). However for normal colorimetry their output of 100-200 microamperes per lumen is quite sufficient, their response with low external resistance is linear, they show little fatigue, have unlimited life, are rugged and compact in construction and require no external stabilized voltage. Of the cells at present available, the spectral response of the barrier layer cell is somewhat better for use in the visible spectrum than that of the photo emissive type. Full information regarding the two types of cell and their operation is set out in brochures supplied by the manufacturers, in particular the RCA Manufacturing Co. Inc. (3) and the Weston Electrical Instrument Corporation (4) while Muller (5) has reviewed fully photo cell types and circuits in common use.

High Vacuum Photo Tube Colorimeters

These colorimeters appeared to offer most promise on account of the greater sensitivity of the high vacuum tube circuits and experiments were first directed to the design of a colorimeter of this type. On the grounds of low cost and simplicity of construction and operation, a circuit described by the manufacturers (RCA Manufacturing Co. Inc. (3)) for matching measurements offered most promise for a laboratory built model. In this A.C. operated two cell circuit balance is obtained electrically by varying the voltage on the photocells which are arranged in series across a reasonably stable voltage source (rectified and smoothed

mains). There is one stage of amplification and a 'magic eye' is used to indicate balance in place of a galvonometer. The electrical components were mounted underneath a well ventilated chassis and the layout of photo cells, lamp and controls was based on that of the Spekker Photoelectric Absorptiometer. However considerable difficulty was experienced with drift due mainly to the heating of components and fluctuations in the line voltage. Small modifications to the original circuit and layout effected very slight improvements and the instrument was only reasonably satisfactory for measuring turbidity and for colorimetric work using blue solutions, the sensitivity decreasing rapidly on moving through the spectrum towards the red. Further, even in these cases the expected degree of accuracy was not obtained and the instrument tended to be unstable. In view of these difficulties which appeared inherent in this type of instrument, the use of vacuum type photo cells was abandoned.

CONSTRUCTION OF A COLORIMETER USING A BARRIER LAYER CELL

Photoelectric colorimeters fall into two main groups, those utilizing a single cell giving a direct galvanometer reading and those using two cells in a balanced type of circuit, in which the balancing is either electrical or optical. A balanced circuit overcomes the necessity for a constant voltage supply for the lamp, since if properly designed it will compensate for fluctuations in the light source and, contrary to general belief, does not necessarily require cells accurately matched for their spectral response (5). At the same time the single cell offers the advantage of simplicity in construction and greater speed and ease of operation and this circuit was chosen as being most suitable for a laboratory built colorimeter.

CONSTRUCTIONAL DETAILS

The photo cell used is a Weston type 594* output being measured on a spot galvanometer† giving a full scale deflection of 50 cm. The internal resistance of this instrument is about 1000 ohms and a parallel resistance of 5000 ohms provides sufficient damping. The galvanometer and scale is mounted in a light tight box separate from the colorimeter.

ABSORPTION CELLS

While test tubes have been used most conveniently as absorption cells in a number of colorimeters their round surface precludes any simple device for sliding a reference cell into place to adjust the instrument and to check for drift. Since the test tubes focus the light it is fundamental to such instruments that the tube be in exactly the same position for each reading, a condition difficult to obtain when mounting on a moveable slide is desired. For this reason flat sided cells were used, two being mounted side by side on a carrier as shown in Fig. 4. The cells are constructed from 2 in. squares of plate glass in the centre of which a hole $1\frac{3}{8}$ in. diameter is drilled, all edges being left unpolished to reduce reflection; 2 in. square lantern slide glass are cemented to either side, a small opening being cut in the top for filling. The cement used depends on the solvents and reagents but Canada Balsam has been found satisfactory for all aqueous solutions and casein glue treated with formaldehyde for organic solvents. The plate glass is available

* Supplied by Standard Telephones and Cables (A'sia) Ltd., Wellington.
† Cambridge pot. Galvanometer Catalogue No. 41157/2.

in various thicknesses, $\frac{5}{16}$ in. being chosen to give a cell capacity of approximately 9 ml. Provided the glasses are clamped together while the cement is still fluid and pressure applied until it is quite set, the variation in width is not significant. The cells do not need to be removed from the instrument but can be emptied by means of a tube attached to a vacuum pump.

The Lamp

To give sufficient light for the densest filters a 40 C.P., 6 volt car headlamp was used. In any colorimeter the output of the photo cell can be adjusted to the required value by reducing the light incident on the cell or by keeping a uniform light intensity and reducing the current developed by means of a resistance network. With the latter method the coloured solution is exposed to a needlessly intense light with the possibility of increased rate of fading. (Since many of the solutions with which it was desired to work fade rapidly, particular attention has been paid in the design of the colorimeter to keeping the light intensity to a minimum.) Reduction of the light intensity was therefore selected and was achieved by means of a diaphragm rather than by varying the supply voltage, since with a lamp of this power there is a noticeable change in hue as the voltage is altered. Provision was also made for moving the lamp nearer to the photo cell when using particularly dense filters. By using a definite lamp position with each group of filters, any errors due to different light paths are eliminated.

The Filters

The filters used are 2 in. square Wratten gelatine filters mounted between lantern slide cover glasses. In use these filters are mounted in a carrier slotted to take two filters. The filters are placed between the lamp and cells in order to reduce fading of the solutions. No difficulty with heating of the filters has been experienced. A metal masking plate fits into the space between the filters and so prevents light reaching the solution and the photo cell except when readings are being taken, thus preventing fading and fatigue respectively. This method is preferable to switching the lamp off as it requires about 5 minutes to reach a stable level of illumination.

The Body of the Colorimeter

The instrument was constructed entirely in metal (mainly light sheet iron) to give rigidity. Figs. 1 and 2 show a general view of the instrument (Fig. 2 including the fluorimetric attachment) while Fig. 3 gives a sectional scale elevation. The base (A) carries a square box fitted to accommodate the photo cell (B) the absorption cells on their carrier (Fig. 4) the filters, diaphragm (C) and the lamp (D). The photo cell fits into a 'pocket' being held in place by the locating screw in the back of the photo cell. The light beam is restricted to a maximum diameter of 1 in. by means of fixed diaphragms (E) and it is not necessary to introduce a lens system to give a closer approach to parallel light. The absorption cell carrier slides through an opening (F) on a solid base (G) so placed that the centre of the cell is in line with the filament of the lamp and the centre of the photo cell. The $1\frac{3}{8}$ in. diameter of the absorption cells allows a latitude of about $\frac{1}{8}$ in. in the placing of the

cells with full diaphragm aperture, the correct placing being indicated by pins at either end of the base with which the carrier makes contact. The filter carrier fits into a slot (H) in the top of the colorimeter next to the diaphragm. The lamp is mounted on a sliding rod (J) through which the leads to the lamp pass to the switch (K). Good ventilation of the lamp house is necessary. The end (L) is removable to give access to the lamp and diaphragm. A cover (removed in Figs. 1 and 2 to show details) protects the photo cell and absorption cells from outside

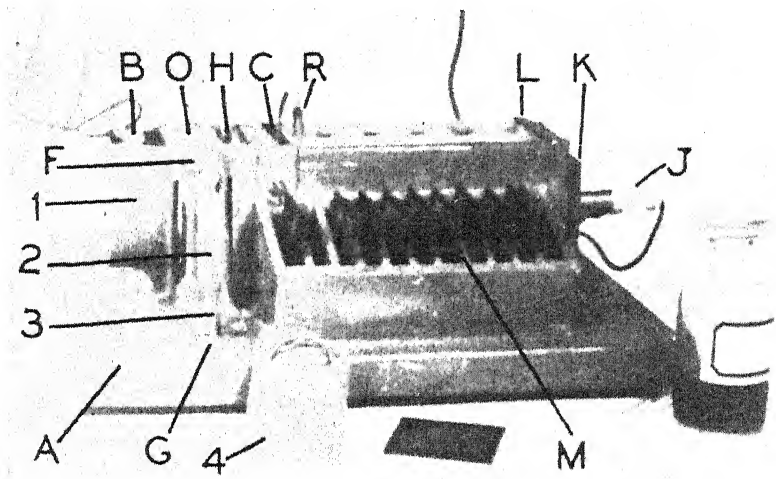


FIG. 1.—The Colorimeter. 1 Photocell holder; 2 Absorption cell carrier; 3 Locating pin; 4 Masking plate.

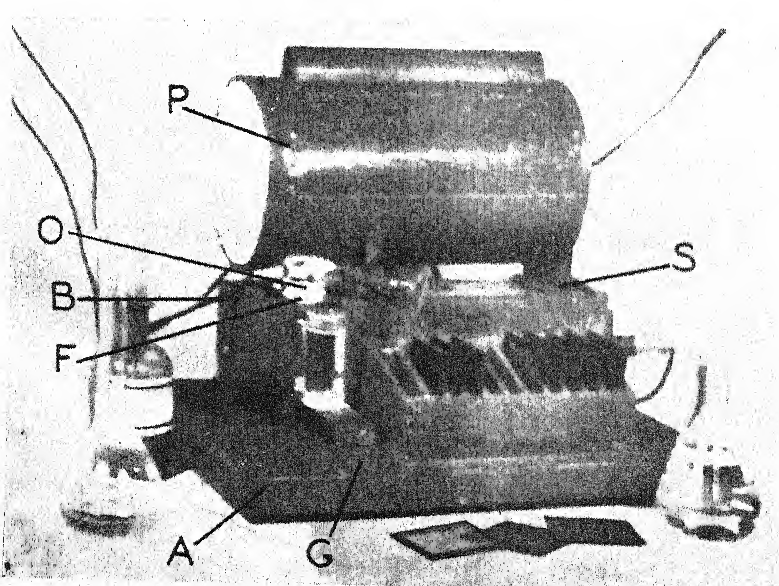


FIG. 2.—The Fluorimeter.

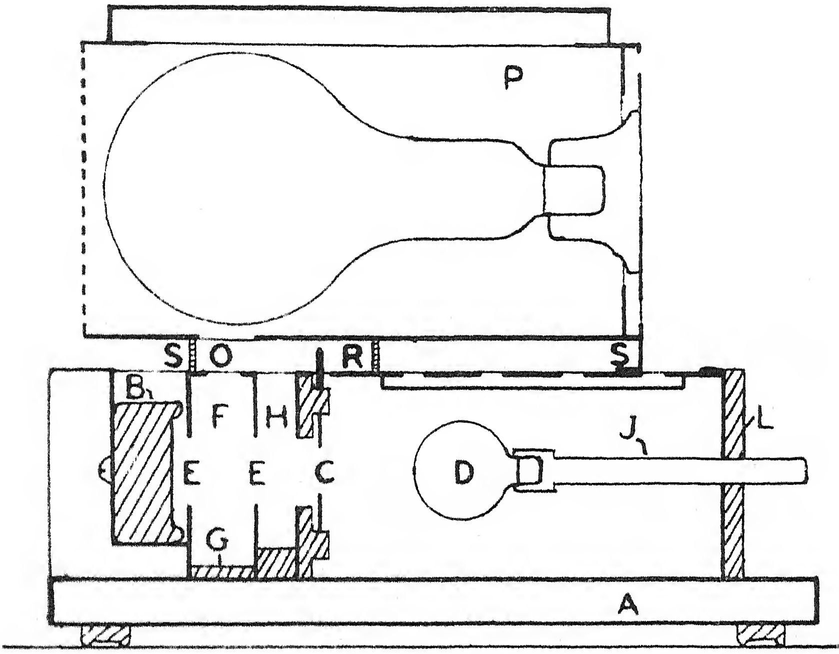


FIG. 3.—Sectional scale elevation (total length 12").

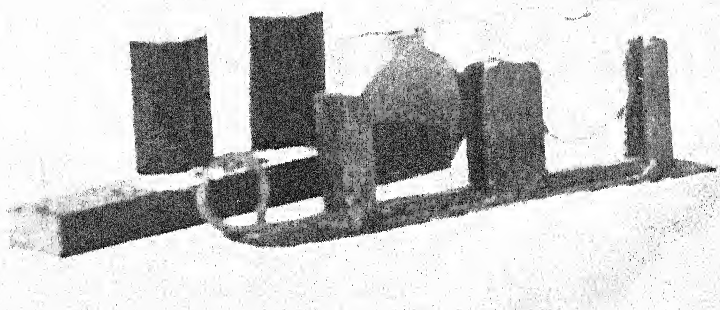


FIG. 4.—The cells and carriers.

illumination and when operating in bright light the opening in this cover is shielded while readings are taken. A rack (M) to carry filters not in use completes the colorimeter portion of the apparatus.

In operation the galvanometer is adjusted to give zero reading with the masking plate in place. Using the appropriate filters, the lamp at the correct position and the reference cell containing distilled water or the pure solvent in place in the light beam, the light intensity is adjusted by means of the diaphragm to give full scale deflection, i.e., 100 per cent. transmission. The other absorption cell containing the test solution is then moved into place and the percentage transmission read directly.

Provision can also be made for the use of test tubes as absorption cells in particular cases where it is desired to follow reactions taking place in test tubes. A wooden block is cut to fit the cell compartment (F). A hole (O) is drilled through the top of the compartment and into the block to accommodate the test tube and a horizontal slot 1 in. × ½ in. is cut through the block to transmit the light as in the Evelyn Colorimeter. The block having been securely screwed in place, the matched test tubes are merely inserted and the transmission measured as before.

FLUORIMETRIC ATTACHMENT

The fluorimeter portion of the apparatus consists of a well ventilated lamp house (P) mounted so that the light shines through the opening (O). This housing is removeable, being attached by a screw (R) and three locating pins (S). The ultra violet source used is a 'Mercra' British Thomson-Houstin 125 watt lamp* which is fitted with a Woods glass filter. (It appears that a more suitable lamp would be a General Electric Type C-H4 (6) which is however not yet available in New Zealand.) The absorption cells already described were not suitable but round straight sided specimen tubes 2 in. × ¾ in. were found to be quite satisfactory. In this case since the light enters the top of the tube the round cell is no objection. Two cells are again mounted on a carrier (Fig. 4) which slides in the same way as the absorption cell carrier, being positioned by the same pins. It is preferable that the diameter of the light beam be slightly smaller than the internal diameter of the tubes to give some latitude in the placing of the carrier. The intensity of the ultra violet is varied by means of a diaphragm. Scattered ultra violet is blocked by placing a wratten filter No. 2A immediately in front of the photo cell.

With a single cell fluorimeter of this type, the chief difficulty encountered is mains voltage fluctuation. The effect of these fluctuations on the ultra violet output depends to a large extent on the type of lamp and the choke used in conjunction with it. Since it is not normally necessary for the output of these lamps to remain absolutely constant most commercial chokes are designed to run near to saturation point. In such cases a voltage surge will result in an increase in lamp current many times greater than the actual voltage change due to the inductance of the choke decreasing as it runs into saturation.

It was found that the operating conditions of the choke supplied with the 'Mercra' lamp were fairly satisfactory since the change in output was only about twice as great as the change in voltage. This is typical of luminous discharge tubes under normal working conditions and cannot be greatly improved by choke design.

* Obtained from the National Electric and Engineering Co. Ltd., Wellington.

The output variation can, however, be considerably reduced by introducing in series with the lamp and choke, a condenser whose reactance is twice that of the choke. With this circuit, since the choke is approaching saturation, an increase in voltage causes the choke reactance to decrease so that the total reactance which is the difference between the reactances of the choke and condenser increases thus opposing the rise in current. Using this network it was possible to reduce the percentage change in output to about one half that of the voltage change. Under normal supply conditions, these small variations in output do not affect the satisfactory working of the fluorimeter. This condenser-choke circuit offers a convenient method of overcoming voltage variations without resorting to self regulating transformers or similar voltage stabilising equipment. It is however necessary to check the lamp current with and without the condenser in series. These should be the same but the tolerance of commercial condensers may be enough to introduce serious errors.

In operation the lamp is allowed about 15 mins. to warm up and reach maximum stable intensity. A cell containing distilled water is placed in the light beam and the galvanometer adjusted to zero. A cell containing a reference solution, e.g., sodium fluorescein, is moved into the beam and the intensity of the ultra violet adjusted to give a convenient scale reading. The zero is then checked and the test solution placed in the light beam. The scale reading corresponding to the flourescence of this solution is expressed as a percentage of that due to the reference solution.

Cost of the Instrument

The approximate cost in New Zealand of the components is :—

Galvanometer and accessories	£9	0	0	
Photo electric cell	4	0	0	
Filters		5	0	each
Constructional materials, absorption cells, etc.	1	0	0	
Ultra violet lamp, choke and condenser ...	9	0	0	

The total cost is therefore, not more than £25.

Acknowledgments

It is the author's pleasure to acknowledge the interest, advice and help of Dr. C. R. Barnicoat during the construction and testing of the instrument, the assistance of Mr. A. J. Dickson in the mechanical design and construction, and the help of Mr. L. E. Mayo of Messrs. Radio (1936) Ltd., Auckland, in designing the choke-condenser circuit.

References

(1) Evelyn (1936): *J. Biol. Chem.*, *116*, 63.
(2) Amplification Circuits for use with Weston Photronic Photoelectric Cells. *Weston Data Sheet No. 169.*
(3) RCA Phototube Manual. *RCA Form PT-20R1.*
(4) "Technical Data on Weston Photronic Cells." Weston Electrical Instrument Corporation.
(5) Muller (1939): *Ind. and Eng. Chem., Anal. Ed.*, *11*, 1.
(6) Mercury Lamp. *General Elecrtic brochure LS-103.*

NOTES ON AZIMUTHS, DISTANCES AND EQUIDISTANT AZIMUTHAL PROJECTIONS IN THE SOUTH PACIFIC

By W. M. JONES, Dominion Observatory, Department of Scientific and Industrial Research, Wellington

(*Received for publication, 17th October, 1947*)

Summary

Tables are now available giving geographical distances, in degrees and minutes, from observatories at Auckland, Wellington, Christchurch, Riverview, Brisbane, Suva, and Apia, to points at 1° intervals over the zone 0°-70° S., 160° E.-170° W. A table has also been compiled giving azimuths and distances from the same observatories to points at 5° intervals over the zone 0°-70° S., 150° E.-155° W. This table enables the construction of equidistant azimuthal projections which will show with fair accuracy the azimuths and distances from the observatories to any point in the zone. For other stations within about 100 miles from any of the observatories, simple corrections can be applied to the distances and azimuths tabulated, without much loss of accuracy.

INTRODUCTION

As scientific work develops in the South Pacific, a sufficiently accurate knowledge of azimuths and distances between two points, or between a station and a series of points, will be increasingly required by investigators in many fields, e.g., in seismology (earthquakes or microseisms), meteorology (long-range location of cyclone-paths), studies of radio transmission conditions and navigation by radio methods, location of aurorae or of meteors, studies of water-waves, tsunamis, or swell, and perhaps, in the future, the paths of rocket projectiles. The accuracy-requirements are variable, but for many purposes it is not necessary to take into account the earth's ellipticity, and many needs will be met by a knowledge of great-circle distances to within a mile or two, and of azimuths to within a few minutes.

In previous papers, (1) and (2), the writer has given tables of four-figure direction-cosines, at 1° intervals of latitude and longitude, which enable the ready compution of distances to points in any latitude over a zone of 60° of longitude. The accuracy attainable is to a minute or two of arc, or a mile or two of distance (except at ranges less than 5°), and the process is simple, even without a calculating machine. A table of geographical distances, in degrees and minutes, computed by this method, has been given for the range 0°-35° S., 160° E.-170° W. in a *Dominion Observatory Bulletin* (3). An extension of this table, from 36° to 70° S., over the same range of longitude, has now been completed, and will be issued as a further *Observatory Bulletin*. The distances are from the principal observatories covering the South Pacific-Auckland, Wellington, Christchurch, Riverview, Brisbane, Suva, and Apia. For points inside the 1° intervals, linear interpolation is adequate for most purposes.

For other stations, within a radius of about 100 miles from any of the abovementioned observatories, it is possible, as indicated below, to make a simple correction to the distance given for the observatory, with but little departure from the accuracy of a mile or two attained in the table. The correction involves an approximate knowledge of the azimuth from observatory to the point considered.

AZIMUTHS

When the distance between station and point considered is not known, azimuths can be calculated from the formula of spherical trigonometry—

$$\tan \alpha = \frac{\sin \theta \tan \gamma}{\sin (b - \theta)}, \text{ where } \tan \theta = \tan a \cos \gamma.$$

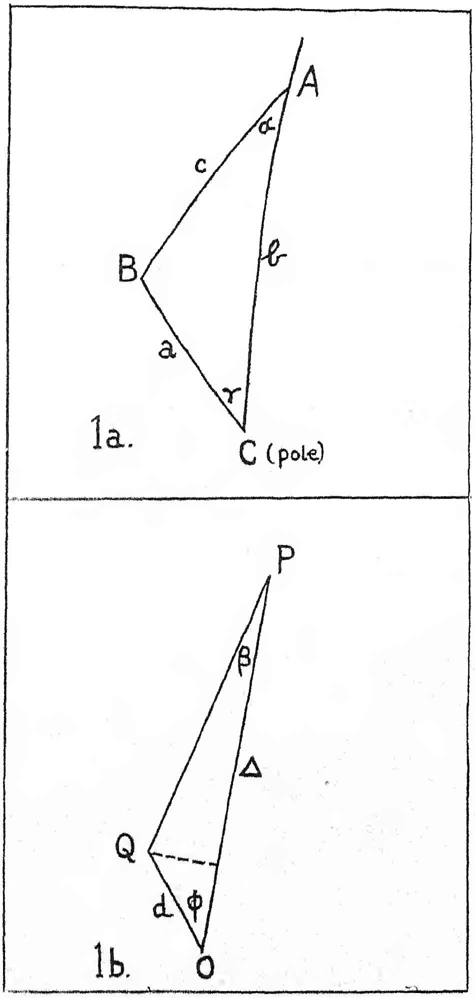


FIG. 1

In Fig. 1a, A is the station, B the point considered, C the South Pole; a is the co-latitude of the point, b that of the station, and **1** the difference in longitude of point and station. The azimuth of B from A, measured clockwise from the north direction, follows, according to the quadrant in which B is situated, from the value obtained for α.

When the distance between station and point is already known (c in the figure), then

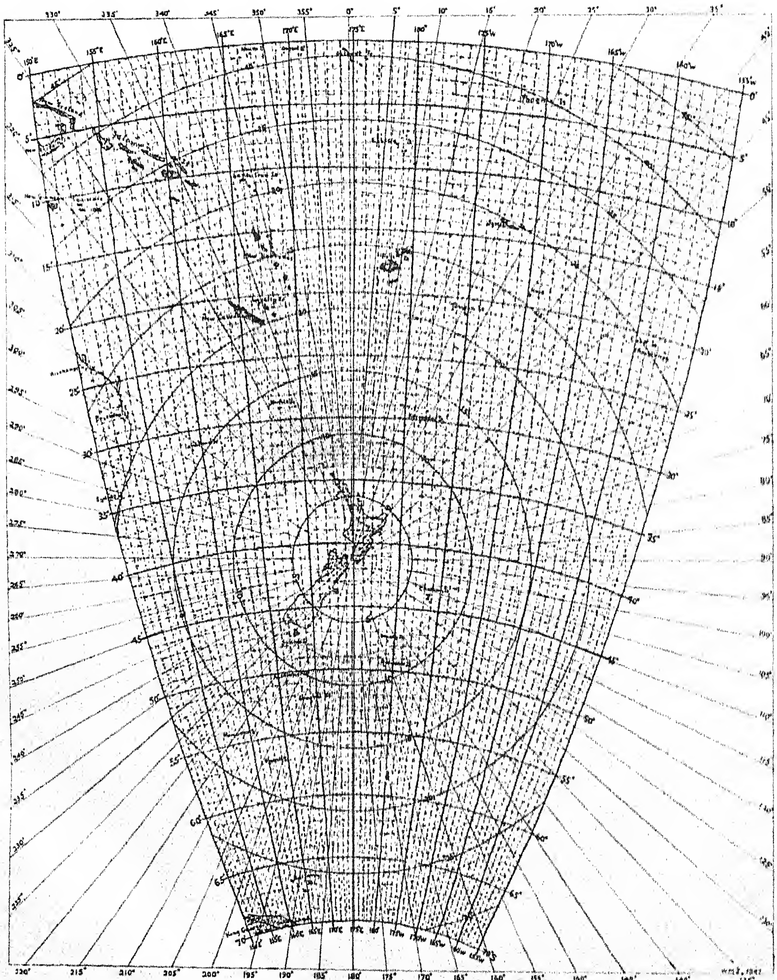
$$\sin \alpha = \frac{\sin a \sin \gamma.}{\sin c}$$

The locus of points with azimuth 90° or 270° is given, from the first formula, as

$$b = \theta, \text{ or } \tan a = \tan b \,/\, \cos \gamma.$$

and can be readily be drawn through its intersections with a succession of meridians, the latitude-values being obtained by substituting successive values of γ.

For the same seven observatories, a table of azimuths, with the corresponding distances, at intervals of 5° in latitude and longitude, has now been completed, and will be issued as an *Observatory Bulletin*. The range is 0°-70° S., 150° E.-155° W., and covers the region of most interest to our South Pacific observatories.



EQUIDISTANT AZIMUTHAL PROJECTION
FROM DOMINION OBSERVATORY, WELLINGTON 41°17'S, 174°46'E
Scale (radial distances only)

FIG. 2

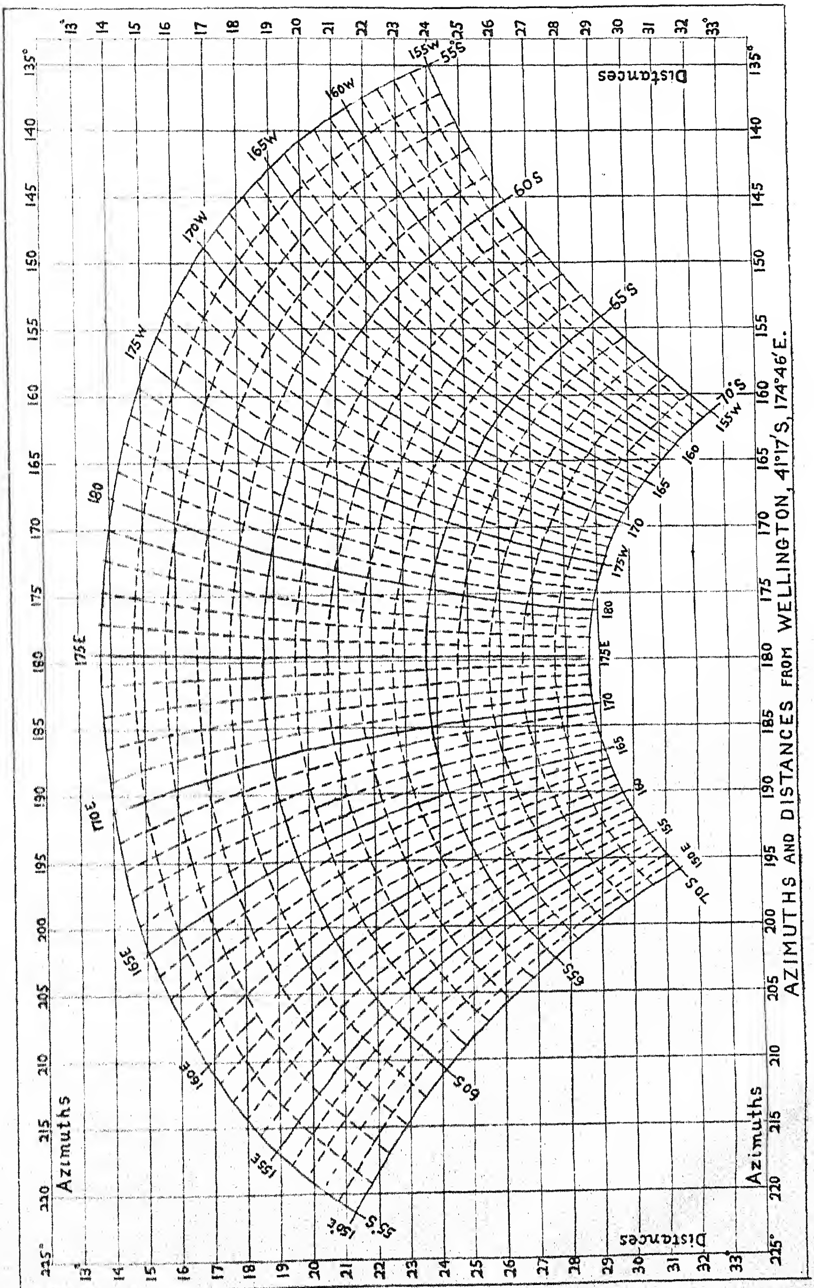

AZIMUTHS AND DISTANCES FROM WELLINGTON, 41°17'S, 174°46'E.
Azimuths
Distances

Fig 3

EQUIDISTANT AZIMUTHAL PROJECTIONS

An equidistant azimuthal projection of the whole earth, based on Makara, has been given by Lee (4), with notes on the use of the above and other formulae in computation. The azimuth-distance table above mentioned can be used as basis for similar projections from the observatories, for the region covered. The graticule is close enough to draw a reasonably large-scale map of the region (say 1° = 1 cm.), with straight lines for each degree of azimuth, and circles for each degree of distance. Then distances can be read off to an accuracy of about 5 miles, and azimuths within 15′ (except close to the centre). A reproduction of such a map for the Dominion Observatory, Wellington, although too small to be of much use for reference, is shown in Fig. 2.

For particular areas, when distortion of land forms does not matter, other methods of plotting, not necessarily projections in the ordinary sense, can be used. For example, the angular scale of azimuth can be multiplied, so that an angle of 5°, for example, represents 1° of actual azimuth-difference. Squared paper can also be used, with distances and azimuths as co-ordinates, and curves drawn on it representing parallels and meridians. An example which might be used in work on aurorae from Wellington is illustrated in Fig. 3.

DISTANCE-CORRECTIONS FOR A DISPLACEMENT FROM THE OBSERVATORIES

When the distances and azimuths from an observatory are known, and the ranges are not too great, a simple correction may be applied to obtain a distance from another station not too far removed from the observatory. The correction is obtained from the plane triangle (see Fig. 1b) instead of the spherical triangle. O is the observatory, Q the new station, and P the point considered. The displacement d and its direction being known, the angle ϕ is found from the known azimuth of P from O, using the equidistant azimuthal projection, or interpolating from the table (great accuracy in estimating ϕ will not be necessary). The correction is d cos ϕ, its sign being apparent from inspection. The greatest error involved in using the plane triangle can be assessed by working out a few examples for points on the periphery of the region covered, for displacements to the north and to the east. For example, for a displacement of 50 miles to the north or to the east of Wellington, the errors in the correction, calculated for a series of 10 points round the periphery of the region, including the corners, were found not to exceed about a minute of arc, or about the order of the possible errors in the original distance-calculations; even for a displacement of 2°, or 138 miles, the maximum error noticed was only 8′. In this case, the observatory is in a fairly central position in the region covered, and somewhat greater errors may arise when it is near the border of the region, but if thought desirable, the matter of maximum error for a particular station can be readily settled, as indicated, in an hour or two. Thus, with the azimuths and distances available from Wellington, Auckland, and Christchurch, distances from almost any point in New Zealand should be obtainable within a few miles by applying the correction d cos ϕ to the value for the nearest of the three observatories.

AZIMUTH-CORRECTIONS FOR SIMILAR DISPLACEMENTS

Using the same plane triangle, the correction for azimuth would be given approximately by

$$\sin \beta = \sin (\beta + \phi). \quad d/\Delta.$$

or when d is small compared with Δ, by

$$\sin \beta = \sin \phi. \quad d/\Delta'$$

The errors involved have not been investigated, but examples for particular cases could be readily calculated.

REFERENCES

(1) JONES, W. M. (1944): Table of Direction-cosines to Four Figures at Intervals of One Degree in Latitude and Longitude over a Zone of 60° of Longitude, and Latitude from 0° to 40°. *N.Z. J. Sci. and Tech.*, *26*, (*Sec. B*), 155.

(2) JONES, W. M. (1947): Additional Table of Direction-cosines, for Latitudes 41°-90°. *N.Z. J. Sci. and Tech.*, *28*, (*Sec. B*), 292.

(3) JONES, W. M. (1945): Table of Geographical Distances. *Dom. Observ. Bull.*, S. 83.

(4) LEE, L. P. (1947): The Equidistant Azimuthal Projection of the Sphere. *N.Z. Geographer*, *3*, 41.

REVIEW.

CARNEGIE INSTITUTION OF WASHINGTON, YEAR-BOOK No. 46, 1946-1947

$1.00 in paper cover, $1.50 in cloth binding, postpaid

This includes the usual business details, the report of the President, Vannevar Bush, and reports of departmental activities under the headings:—

ASTRONOMY (Mt. Wilson Observatory).

TERRESTRIAL SCIENCES: Geophysical Laboratory, Dept. of Terrestrial Magnetism, and Special Projects.

BIOLOGICAL SCIENCES: Plant Biology, Embryology, Genetics.

HISTORICAL RESEARCH.

with bibliographies of publications.

Only a few of the many items of interest in these reports are selected.

Babcock, in continued investigations of the general magnetic fields of stars, has surveyed likely ones down to the sixth magnitude, finding fields stronger than 1000 gauss in several, and in one a polar field of 5500 gauss.

The Geophysical Laboratory has employed a new type of pressure apparatus in the study of equilibrium relations in hydrous mixtures, especially the magnesia-silica-water system. The pressures have been up to 30,000 lbs. per square inch, and temperatures up to 900°c., and the conditions of formation of igneous and metamorphic rocks should be more clearly understood as this work is extended.

An achievement of the Department of Terrestrial Magnetism has been the association of marked increases of the measured intensity of cosmic radiation with solar flares,—three cases of which have been noticed in ten years. A theory considered is that of accelerating action associated with the flare, possibly by a local rate of change of magnetic field, as in a betatron accelerator.

The study by new methods of the faint residual magnetism in glacial silts has indicated that the earth's magnetic field has not changed much during the past 30,000 years.

On the biological side, studies of the fundamental process of photo-synthesis in plants lead to the conclusion that this process has undergone little change in the long course of evolutionary history; for example, the photo-synthetically active pigments of present-day green algae are the same as those possessed by their fossil ancestors of several hundred million years ago.

The grass-breeding programme for the purpose of producing a better range grass has resulted in nearly three hundred interspecific hybrids, some of which show high promise in respect of yield, resistance to disease, and activity in dry summer weather. It was found, unexpectedly, that two-thirds of the hybrids between asexual parents were themselves sexual.

The Department of Genetics has applied their aerosol method to test the power of various cancer-producing agents to bring about mutations in genes. Most of the carcinogens tested have been found to be mutagenic, but chemically related substances which are not carcinogenic do not produce mutations. These results are relevant to the hypothesis that cancer may originate through a gene mutation occurring in a somatic cell.

The Department of Embryology has employed tracer techniques, one with radioactive sodium and heavy water to give the proportion and distribution of water in the bodies of newborn infants. The newborn infant is found to be 74.6 water, the extracellular water being 43.5 per cent. of the body weight. These findings reinforce other evidence that the ratio of water within the cells to extracellular water increases as growth goes on.

Light is being thrown on problems of advanced pregnancy and parturition by measurements of the physical forces involved as the uterus accommodates to its growing contents. Sensitive strain gages have been developed to give a tape record of uterine contractions.

In Historical Research, work at Nebaj in the Guatemala highlands has disclosed works of art spanning seven or eight centuries, including the finest example of Maya jade carving yet found. An expedition to Bonampak in Chiapas has studied frescoes, lavish in detail, dating from the eight century.

The Palomar Mountain Observatory, with the 200-inch telescope, expected to be completed in 1948, will be operated in co-operation with the Mount Wilson Observatory, by an agreement between the Carnegie Institution and the California Institute of Technology.

The Observatories at Watheroo and Huancayo have been transferred by gift to the Governments of Australia and of Peru, respectively. This is in consequence of the new emphasis of the Dept. of Terrestrial Magnetism on laboratory and experimental work, and of the recognition that the collection of geophysical data over long periods is now widely accepted as an appropriate activity for a governmental scientific bureau. The policy of the Department is now "to emphasize creative work, ideas with new potentialities, and work which lies on the front lines of knowledge." —W. M. J.

INDEX

VOLUME 29, SECTION B